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International Space Station Evolution Data Book

Volume II. Evolution

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Foreword

This document provides a focused and in-depth look at the opportunities and drivers for the enhancement and evolution of the International Space Station (ISS) during its assembly and until its assembly complete (AC) stage. These enhancements would expand and improve the current baseline capabilities of the ISS and help to facilitate the commercialization of the ISS by the private sector. The intended users of this document include the ISS organization, the research community, other NASA programs and activities, and the commercial sector interested in opportunities that the ISS offers.

The purpose of this document is threefold. First, it provides a broad integrated systems view of the current baseline design of the ISS systems and identifies potential growth and limitations of these systems. Second, it presents current and future options for the application of advanced technologies to these systems and discusses the impacts these enhancements may have on interrelated systems. Third, it provides this information in a consolidated format to research and commercial entities to help generate ideas and options for developing or implementing new technologies to expand the current capabilities of ISS and to assist them in determining potential beneficial uses of the ISS. The content of this document ventures beyond the current designs and capabilities of the ISS towards its future potential as a unique research platform and engineering test bed for advanced technology. It provides an initial source of information to help stimulate the government and private sectors to develop a technological partnership in support of the evolution and commercialization of the ISS.

The ISS Evolution Data Book is composed of two volumes. Volume I contains the baseline descriptions with section 1 being an introduction to Volume I. Section 2 provides an overview of the major components of the ISS. Section 3 summarizes the ISS baseline configuration and provides a summary of the functions and potential limitations of major systems. Section 4 outlines the utilization and operation of the ISS and furnishes facility descriptions, resource time-lines and margins, and a logistics and visiting vehicle traffic model. Volume II contains information on future technologies, infrastructure enhancements, and future utilization options and opportunities. Section 1 is an introduction to Volume II. Section 2 identifies the advanced technologies being studied by the Preplanned Program Improvement (P^{3}I) Working Group for use on ISS to enhance the operation of the station. Section 3 provides information on the advanced technologies that go beyond the efforts of the P^{3}I Working Group. Section 4 covers the commercialization of the ISS. Section 5 provides options for advanced research opportunities. Section 6 summarizes the analysis performed for several design reference missions (DRM's) that are being considered for post AC utilization and enhancements. Section 7 provides utilization opportunities that may enhance the efforts of the human exploration and development of space (HEDS) missions. Section 8 provides a synopsis of the derived synergistic technology investment areas that are being considered for ISS utilization.

The contents of this document were gathered by the Spacecraft and Sensors Branch, Aerospace Systems Concepts and Analysis Competency, Langley Research Center (LaRC), National Aeronautics and Space Administration (NASA). This document will be updated as the current configuration of the ISS evolves into its AC state and beyond. Much of the baseline configuration description is derived from the International Space Station Familiarization Document, TD9702, ISS FAM C 21109, NASA Johnson Space Center December 1997.

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Acronyms and Abbreviations

ABC	audio bus coupler
AC	assembly complete
ACBSP	assembly complete baseband signal processor
Acc	accessory
ACESE	attitude control and energy storage experiment
ACRFG	assembly complete radio frequency group
ACRV	advanced crew return vehicle
ACS	assembly contingency subsystem
ACS	attitude control system
ACS	atmosphere control and supply
ACT	advanced communications tower
ACU	arm computer unit
ADAM	Able deployable articulated mast
AEC	air evaporation closed cycle
AERCam	autonomous EVA robotic camera
AFDIR	automated fault detection, isolation, and recovery
AL	airlock
AP	attached payload
APAS	androgynous peripheral attachment system
APM	attached pressurized module
APS	automated payload switch
AR	atmosphere revitalization
ARCU	American to Russian converter unit
ARIS	active rack isolation system

ASCR	assured safe crew return
ASI	Italian Space Agency (Agenzia Spaziale Italiana)
ATCS	active thermal control system
ATM	asynchronous transmission mode
ATU	audio terminal unit
ATV	automated transfer vehicle
AUAI	assembly-contingency/UHF audio interface
avg	average
AVU	artificial vision unit
AVU CCD	artificial vision unit cursor control device
AZ	azimuth
BCDU	battery charge-discharge unit
BEE	basic end effector
BGA	beta gimbal assembly
BSP	baseband signal processor
BTF	biotechnology facility
C&C	command and control
C&DH	command and data handling
C&T	communication and tracking
C&TS	communication and tracking system
C&W	caution and warning
CADU	channel access data unit
Cal	calibration

CAM	centrifuge accommodation module
CBM	common berthing mechanism
CCDB	configuration control database
CCTV	closed circuit television
CDRA	carbon dioxide removal assembly
CEB	combined electronics box
CEU	control electronics unit
CH	collection hardware
CHeCS	crew health care system
CHIA	cargo-handling interface adapter
CHRS	centralized heat removal system
CIR	combustion integrated rack
CLA	capture latch assembly
CMG	control moment gyroscope
CMS	carbon molecular sieve
COF	Columbus Orbital Facility
comm	communication
cont	continued
COR	communications outage recorder
CPU	central processing unit
CRPCM	Canadian remote power control module
CRV	crew return vehicle
CSA	Canadian Space Agency
CTB	cargo transfer bag
CVIU	common video interface unit

DA	Deutsche Aerospace
DAC	design analysis cycle
DAIU	docked audio interface unit
D&C	display and control
DC	docking compartment
dc	direct current
DCC	dry cargo carrier
DCSU	direct-current switching unit
DDCU	direct-current-to-direct-current converter unit
DES	data encryption standard
DLR	German Space Agency (Deutschen Zentrum für Luft- und Raumfahrt)
DOD	depth of discharge
DRM	design reference mission
DSM	docking and stowage module
EACP	EMU audio control panel
EACP	EVA audio control panel
ECCS	expendable charcoal catalyst system
ECLS	environmental control and life support
ECLSS	environmental control and life support system
ECOMM	early communication
ECS	early communication subsystem
ECU	electronics control unit
EDO	extended duration orbiter
EDV	electronic depressurizing valve

EETCS early external thermal control system

EEU equipment exchange unit

EF exposed facility

EFPL exposed facility payload

EFU exposed facility unit

EL elevation

ELM-ES experiment logistics module - exposed section

ELM-PS experiment logistic module - pressurized section

ELS enviornmental life support

EM experiment module

EMMI EVA man-machine interface

EMU extravehicular mobility unit

EPCE electrical power-consuming equipment

EPS electrical power system

ERA European robotic arm

ER&T engineering research and technology

ESA European Space Agency

ETCS external thermal control system

ETOV Earth-to-orbit vehicle

ETVCG external television camera group

EUE experiment unique equipment

EVA extravehicular activity

EVR extravehicular robotics

EVSU external video switch unit

ExP EXPRESS pallet

ExPA	EXPRESS pallet adapter
ExPCA	EXPRESS pallet control assembly
EXPRESS	expediting the processing of experiments to Space Station
ExPS	EXPRESS pallet system
4BMS	four-bed molecular sieve
FCF	fluids and combustion facility
FDIR	fault detection, isolation, and recovery
FDS	fire detection and suppression
FF	free flyer
FGB	functional cargo block
FIR	fluids integrated rack
FLEX	control of flexible construction systems
flex	flexible
F-O	fiber-optic
FRCS	forward reaction control system
FSE	flight support equipment
g	gravity or gravitational unit
GASMAP	gas analysis system for metabolic analysis of physiology
GBF	gravitational biology facility
GFI	ground fault interrupter
GLONASS	global navigation satellite system
GN&C	guidance, navigation, and control
GPS	global positioning system

GRC John H. Glenn Research Center at Lewis Field

GUI graphical user interface

Hab habitation module

HDR high data rate

HDTV high-definition television

HEDS Human Exploration and Development of Space

HGA high gain antenna

HRDL high rate data link

HRF human research facility

HRFM high rate frame multiplexer

HRM high rate modem

HTL high-temperature loop

HTV H-II Transfer Vehicle

IAA intravehicular audio assembly

IAC internal audio controller

IAS internal audio subsystem

ICC integrated cargo carrier

ICD instrument control document

ICK insert contaminant kit

ICM interim control module

IDA integrated diode assembly

IEA integrated equipment assembly

IF intermediate frequency

I/F	interface
IFHX	interface heat exchanger
IMCA	integrated motor controller assembly
IMMI	IVA man-machine interface
INPE	National Institute for Space Research – Brazil (Instituto Nacional de Pesquisas Espaciais)
I/O	input/output
IOCU	input/output controller unit
IP	International Partners
IR	infrared
ISPR	international standard payload rack
ISS	International Space Station
ISSA	International Space Station assembly
ITA	integrated truss assembly
ITCS	internal thermal control system
ITS	integrated truss structure
IVA	intravehicular activity
IVSU	internal video switch unit
JEM	Japanese experiment module
JEM RMS	JEM remote manipulator system
JEU	joint electronics unit
JSC	Lyndon B. Johnson Space Center
KhSC	Khrunichev Space Center
Ku-band	Ku-band subsystem

Lab	laboratory module
LAN	local area network
LaRC	Langley Research Center
LCA	loop crossover assembly
LCA	Lab cradle assembly
LDM	logistics double module
LDR	low data rate
LDU	linear drive unit
LEE	latching end effector
LGA	low gain antenna
LOS	loss of signal
LSG	life sciences glove box
LSM	life support module
LSS	life support system
LT	laptop
LTL	low-temperature loop
LTU	load transfer unit
LVLH	local-vertical-local-horizontal

MA	main arm
maint	maintenance
MATE	multiplexer/demultiplexer application test equipment
MBS	mobile remote servicer base system
MBSU	main bus switching unit
MCAS	MBS common attachment system

MCC	Mission Control Center
MCC—H	Mission Control Center—Houston
MCC—M	Mission Control Center—Moscow
MCS	motion control system
MCU	MBS computer unit
MDM	multiplexer demultiplexer
MELFI	minus eighty life sciences freezer/refrigerator for ISS
MF	multifiltration
MFU	multifiltration unit
MHI	Mitsubishi Heavy Industries, Ltd.
min	minimum
MLE	middeck locker equivalent
MLI	multilayer insulation
MMCC	metal monolith catalytic converter
MM/OD	micrometeoroid/orbital debris
MOD	mission operation directorate
MPLM	multipurpose logistics module
MPV	manual procedure viewer
MSC	mobile servicing center
MSD	mass storage device
MSFC	George C. Marshall Space Flight Center
MSG	microgravity science glove box
MSRF	materials science research facility
MSRR	materials science research rack
MSS	mobile servicing system

MT	mobile transporter
MTCL	MT capture latch
MTL	moderate temperate loop
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NC	nozzle closed
NIA	nitrogen interface assembly
NO	nozzle open
NRL	Naval Research Laboratory
OCA	orbiter communications adapter
OCCS	onboard complex control system
OFTS	orbital flight targeting system
OMS	orbital maneuvering system
OPS	operations
ORU	orbital rotational unit
ORU	orbital replacement unit
OSTP	onboard short-term plan
OTCM	ORU tool changeout mechanism
P&S	pointing and support
P^3I	Preplanned Program Improvement
PAA	phased array antenna
PAS	payload attachment system
PCS	portable computer system

PDA power distribution assembly

PDGF power data grapple fixture

PEHB payload Ethernet hub

PEHG payload Ethernet hub gateway

PFC pump and flow control

PFCS pump and flow control subassembly

PG Product Groups

PIU payload interface unit

PL payload

PM pressurized module

PM propulsion module

PMA pressurized mating adapter

PMAD power management and distribution

POA payload/ORU accommodation

POIC payload operations integration center

POP payload operations plan

PPA pump package assembly

PRLA payload retention latch actuators

PTCS passive thermal control system

PTU pan tilt unit

PU panel unit

PV photovoltaic

PVA photovoltaic array

PVCU photovoltaic control unit

PVM photovoltaic module

PVR photovoltaic radiator

PVT pressure-volume-temperature

PVTCS photovoltaic thermal control system

QD quick disconnect

R/A return air

RAIU Russian audio interface unit

RAM random access memory

RBI remote bus isolator

RCS reaction control system

R/D receiver/demodulator

ref reference

RF radio frequency

R/F refrigerator/freezer

RGA rate gyro assembly

RHC rotational hand controller

RHX regenerative heat exchanger

RIC rack interface controller

RM research module

RMS remote manipulator system

RO reverse osmosis

ROEU remotely operable electrical umbilical

ROS Russian Orbital Segment

RPC remote power controller

RPCM	remote power controller module
RPDA	remote power distribution assembly
rpm	revolutions per minute
R-S	receive-send
RSA	Russian Space Agency
RSC-E	Rocket Space Corporation-Energia
RSP	resupply stowage platform
RSR	resupply stowage rack
RSU	roller suspension unit
RTAS	Boeing/Rocketdyne truss attachment system
RVE	rack volume equivalent
RVCO	RVE closeout
RWS	robotics workstation

SA	Spar Aerospace
SAREX	Shuttle amateur radio experiment
SARJ	solar alpha rotary joint
SAW	solar array wing
S-band	S-band subsystem
SCU	sync and control unit
SFA	small fine arm
SFCA	system flow control assembly
SGANT	antenna group
SIR	standard interface rack
SM	service module

SMMOD	service module micrometeoroid and orbital debris shield
SOC	state of charge
SPDA	secondary power distribution assembly
SPDM	special purpose dexterous manipulator
spec	specification
SPG	single point ground
SPP	science power platform
SPV	single-pressure vessel
SRMS	Shuttle remote manipulator system
SRTM	Shuttle radar topography mission
SSAS	segment-to-segment attachment system
SSBRP	Space Station Biological Research Project
SSC	Station support computer
SSCS	space-to-space communication system
SSP	Space Shuttle Program
SSRMS	Space Station remote manipulator system
SSSR	space-to-Space-Station radio
SSU	sequential shunt unit
STS	Space Transportation System
SVS	space vision system
TBD	to be determined
TBS	to be supplied
TCCS	trace contaminate control subassembly
TCP/IP	transmission control protocol/internet protocol

TCS	thermal control system
TDRS	tracking and data relay satellite
TDRSS	tracking and data relay satellite system
TEA	torque equilibrium attitude
TEF	thermal electric freezer
TH	TransHab
THC	temperature and humidity control
THC	translational hand controller
TRC	transmitter/receiver/controller
TRL	technology readiness level
TSM	transport servicing module
TUS	trailing umbilical system
TWMV	three-way mix valve
UCC	unpressurized cargo carrier
UCCAS	unpressurized cargo carrier attachment system
UCS	ultrahigh frequency communication system
UDM	universal docking module
UF	utilization flight
UHF	ultrahigh frequency
ULC	unpressurized logistics carrier
UMA	umbilical mechanism assembly
UOP	utility outlet panel
UP	urine processor
USAF	United States Air Force

USOS	U.S. on-orbit segment
VASIMAR	variable specific impulse magnetoplasma rocket
VAX	virtual architecture extendable
VBSP	video baseband signal processor
VCD	vapor compression distillation
VDS	video distribution system
VRA	volatile removal assembly
VSU	video switch unit
VTR	video tape recorder
WM	waste management
WORF	window observational research facility
WRM	water recovery and management
W/S	workstation
WSGS	White Sands Ground Station
WV	work volume
XPNDR	standard TDRSS transponder
XPOP	*X*-axis perpendicular to orbit plane
ZOE	zone of exclusion
ZEM	Z1 experiment module
ZSR	zero-g stowage rack

1. Introduction

The International Space Station (ISS) will provide an Earth-orbiting facility that will accommodate engineering experiments as well as research in a microgravity environment for life and natural sciences. The ISS will distribute resource utilities and support permanent human habitation for conducting this research and experimentation in a safe and habitable environment. The objectives of the ISS program are to develop a world-class, international orbiting laboratory for conducting high-value scientific research; to provide access to the microgravity environment; to develop the ability to live and work in space for extended periods; and to provide a research test bed for developing advanced technology for human and robotic exploration of space.

The current design and development of the ISS has been achieved through the outstanding efforts of many talented engineers, designers, technicians, and support personnel who have dedicated their time and hard work to producing a state-of-the-art Space Station. Despite these efforts, the current design of the ISS has limitations that have resulted from cost and technology issues. An initiative is currently underway to look beyond the baseline design of the ISS and determine solutions to these limitations. The needs of the ISS are being assessed, prioritized, and worked to be resolved. The ISS must evolve during its operational lifetime to respond to changing user needs and long-term national and international goals.

As technologies develop and user needs change, the ISS will be modified to meet these demands. Volume II includes discussions which address the advanced technologies being investigated for use on the ISS and potential commercial utilization activities that are being examined. Included in this document are investigations of proposed design reference missions (DRM's) and the technologies being assessed by the Preplanned Program Improvement (P^3I) Working Group. As these investigations progress and the ISS evolves, this document will be updated to keep all interested parties informed of the latest developments.

This information is general and does not provide the relevant information necessary for detailed design efforts. This document is meant to educate readers about the ISS and to stimulate the generation of ideas for the enhancement and utilization of the ISS either by or for the government, academia, and commercial industry. This document will be kept as up-to-date as possible. Revisions to this document will be made as necessary to ensure that the most current information available is accessible to the users of this document.

The developers of this document welcome comments, questions, or concerns regarding the information contained herein. We are looking for input that will enhance sparse areas of the document with additional information, as well as suggestions for refining areas that may contain excessive information outside the scope of this document. Please direct any issues or suggestions regarding the ISS Evolution Data Book to

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2. Advanced Technologies and Utilization Opportunities

2.1. P^{3}I Technologies

The Preplanned Program Improvement (P^{3}I) Technologies Working Group consists of technical experts from most of the NASA centers. The goals of the P^{3}I program are to plan and implement ISS program improvements which substantially contribute to the following objectives:

- Enhanced research productivity and capability
- Increase reliability, maintainability, and sustainability
- Improve operational capability and reduce costs
- Synergistically support Agency strategic objectives

These objectives encompass the reduction of overall costs and ground infrastructure required to operate the ISS, enablement and support for the use of ISS as a technology test bed for Station capability enhancements and for general crosscutting technologies (i.e., for other NASA and government program support, commercial development, satellite or exploration probe system technologies), and the enablement and support of future human space utilization and development.

2.1.1. Program Activites and Process

ISS Chief Engineer's Office leads a team that reviews, identifies, and prioritizes P^{3}I program content. The team has the responsibility to prioritize and make funding recommendations based on the following evaluation criteria:

1. Utilization capability and value enhancement
2. Significant systems performance improvement
3. Logistics (upmass and downmass) and on-orbit stowage reductions
4. Resource use and operating cost reductions
5. Leveraging from or with other ISS utilization or other program activities

The team meets semiannually to review content to support payload operations plan (POP) calls. Participation includes all human space flight centers and major programs as follows:

- ISS Chief Engineer's Office—Team Lead
- ISS Vehicle, Mission Integration, Operations, and Payloads Offices
- Johnson Space Center (JSC) Engineering Directorate, Technology Transfer, and Commercialization Offices
- JSC Exploration Office

- NASA Headquarters, Codes M, U, and S

- Other NASA Centers

- Department of Defense, Department of Energy, and other Government Organizations

- International Partners (IP) Representatives

The improvements presented are examples of the technologies which the P^3I process has identified as having a high priority or which were previously selected through the Engineering Research and Technology Program. These examples are divided into two groups: near term and long term. The near-term examples are the technologies and projects that have been studied for feasibility, recommended to management for funding, but do not represent a funding commitment in the NASA budget process. The long-term examples are the technologies and projects that are being considered as possible improvements to the ISS but still need feasibility studies and further development. The long-term projects could be candidates for future design reference missions. (See section 5.)

2.1.1.1. Near-Term Examples

2.1.1.1.1. Enhanced Communications

The enhancement for the communications are described in the following sections.

2.1.1.1.1.1. Ku-band forward link. The Ku-band forward link will provide 3 additional years of required functionality from flights 6A through UF-5 for video teleconferencing and two-way computer file transfer to onboard operations local area network (OPS LAN).

2.1.1.1.1.2. Subsystems computer OPS LAN. An office support-type laptop will be connected to a centralized server via a wireless radio frequency (RF) LAN (no connection to the 1553 data bus). The laptop will include software such as word processing, E-mail package, graphics viewer, a manual procedure viewer (MPV), an onboard short-term plan (OSTP) viewer (time-line), World-map application. The hardware platform will be the same as the portable computer system (PCS) (IBM 760 laptop computer).

2.1.1.1.1.3. ISS communications ground systems upgrade. The ISS communications ground systems upgrade will add Ku-band uplink with command, voice, video, and file transfer capability. It will provide 150 Mbps downlink with four channels of compressed video, will increase the payload operations integration center (POIC) to support new uplink capabilities and compressed video, will upgrade links between White Sands Ground Station (WSGS), JSC, and Marshall Space Flight Center (MSFC) to support increased data rates, and will upgrade WSGS front-end (level 0 processing) migration to support increased Space Station data rates.

2.1.1.1.1.4. Phased array antenna. A phased array antenna (PAA) demonstration is planned for the Space Shuttle with implementation of this capability as part of the Shuttle upgrade planning. Installation on the ISS would have required significant modifications to the ISS for which funds were not available in the desired time frame. Interest still remains to find a way to install and begin testing PAA capability on the ISS.

2.1.1.1.1.5. Communications outage recorder. The communications outage recorder (COR) will provide 240 hr of payload data downlink coverage and will require the addition of a high rate data recorder which can be played back during tracking and data relay satellite system (TDRSS) access periods. Outage periods can be as long as 20 min with payload data downlink demands up to 40 Mbps during that period.

2.1.1.1.2. Flywheel Energy Storage

A solar-energy-driven motor spins up during sunlit hours to between 50K and 100K rpm to generate current for subsystem power needs in darkness; therefore, an energy storage system will be needed. Rotational momentum will also be used for attitude control. The sponsors for the flywheel energy storage project are the Glenn Research Center (GRC) and the USAF Research Laboratory.

2.1.1.1.3. Maintenance and Upgrades for Multiplexer/Demultiplexer 386 Processor

Study funding has been approved for replacement of the 386-based processor with a new processor based on concern for future growth of central processing unit (CPU) requirements and availability of parts. Flight hardware development funding will begin in 2001 with operational implementation in 2004, 2007, and 2012.

2.1.1.1.4. Ada Compiler Upgrade

Study funding has been approved for an Ada compiler upgrade. The current compiler runs on a VAX machine in a Honeywell-provided MATE and is a retired product. A multistep upgrade plan for the compiler will increase the productivity of the programming staff including faster compilations (factor of 10), will remove conflicts due to multiuse of program MATE resources, and will evaluate changes in "object" code to understand reverification requirements for flight load.

2.1.1.1.5. Autonomous Extravehicular Activity Robotic Camera With Sensors for Leak Detection

The autonomous extravehicular activity (EVA) robotic camera (AERCam) with sensors for leak detection, a free-flying beach ball with cameras, was successfully demonstrated on STS-87 in January 1998. AERCam II is scheduled to be flight demonstrated in 2000. Development of sensors for leak detection and additional control for autonomous flight are ongoing, with flight experiment slated for flight UF-3 in 2002.

2.1.1.1.6. Metal Monolith Catalytic Converter

The metal monolith catalytic converter (MMCC) uses high cell density, short channel length metal monoliths, and specialized catalytic coating processes. It will extend the service life of the catalytic oxidizer orbital replacement unit (ORU) by at least 5 yr and the charcoal bed service life by 2 to 3 yr and will provide a 41-percent power savings. The MMCC system will provide a 98-percent reduction in recovering from a poisoning event.

2.1.1.1.7. Mass Storage Device Upgrade

A study is in process to determine the feasibility of replacing the mass storage device (MSD) with memory boards in the multiplexer-demultiplexer (MDM) because of reliability concerns with enhanced MDM mechanical disk MSD.

2.1.1.1.8. Sidewall Logistics Carrier

The sidewall logistics carrier is one option being investigated to alleviate oversubscription of attached payloads desiring a flight to the ISS and an installation location.

2.1.1.1.9. Battery Life Enhancements

Developments in advanced batteries are being studied. If the flywheel is successful, many of the batteries onboard the ISS may be replaced by the flywheels. However, a need to maintain some batteries to accommodate some contingency modes may still exist.

2.1.1.2. Long-Term Examples

2.1.1.2.1. Advanced Filters for Water and Air Processing

Advanced filters for water and air processing are aimed at reducing upmass and crew time required for filter changeout for the environmental control and life support system (ECLSS). These filters are targeted for operational implementation on ISS in the 2001–2002 time frame.

2.1.1.2.2. Phase III Communications Upgrade

A communications system needs to be developed to support expected data downlink demand up to 3 Mbps with short burst demands up to 1 Gbps. An antenna system could be provided by a commercial supplier or NASA may lease services from one or more commercial suppliers for expanded data downlink needs.

2.1.1.2.3. Advanced Remote Power Controller Module

Reliability failure rate predictions indicate that the remote power controller module (RPCM), an ORU, is one of the drivers for maintenance upmass and crew time. This ORU is also part of the ISS systems upgrade focus of P^3I, with study funding slated to begin in 2001 and operational implementation in 2010.

2.1.1.2.4. TransHab

TransHab is an inflatable module approach that will provide a means to launch a module in a stowed configuration and once deployed could expand the ISS volume substantially. It will also increase the space to provide additional opportunities for testing advanced life support and other technologies.

2.1.1.2.5. Hall Thruster for Orbit Maintenance

The Hall thruster is a solar electric propulsion system using the Hall current and its induced magnetic field to generate a thrust force. These devices have an extremely high specific impulse (1000 to 2000 sec) and very low thrust. This is one of the synergistic technology areas of the Human Exploration and Development of Space (HEDS) Program with a flight technology demonstration slated for 2003 and 2004. The sponsors of this effort are GRC and the USAF.

2.1.1.2.6. Stowage Enhancement Study

Options for soft stowage are being worked as part of the early assembly flight planning. Because the current lack of stowage is a potentially critical issue, recommendations for an overall stowage increase, specifically for payloads, are needed. Commercial options also need to be considered. No current funding is in place for a long-term study.

2.1.1.2.7. Logistics Efficiency Enhancement

In-house assessments of logistics improvement options, such as Shuttle/SPACEHAB/multipurpose logistics module (MPLM) enhancements, use of other autonomous transport vehicles, commercial offers, will be conducted. No current funding is in place for this study.

2.1.1.2.8. Ammonia Loop Pump Module Reliability Assessments

The current pump module has a failure rate of one failure every 2 yr. Failure causes the loss of 50 percent of the ISS power, and the ISS then becomes zero-failure tolerant for survival. Before proceeding with assessment and identification of options for resolution, funds have to be available.

2.1.1.3. Future Technologies

Numerous other technologies have been identified as resolutions to ISS needs. These technologies, although represented in the P^3I road maps, are not all being investigated at this time. The P^3I Working Group assesses and prioritizes the ISS needs and presents recommendations to NASA Headquarters for funding approval.

2.1.2. P^3I Road Maps

Figures 2.1-1 to 2.1-6 represent schedules for technology improvement needs, which, in some cases, have synergistic links with improvements in the systems road maps and, in other cases, represent other improvements desired but not yet recommended or covered by other payload project funding. Each figure outlines the current P^3I technologies that are on the table, and along the left-hand side of the figure are the subcomponents of each technology.

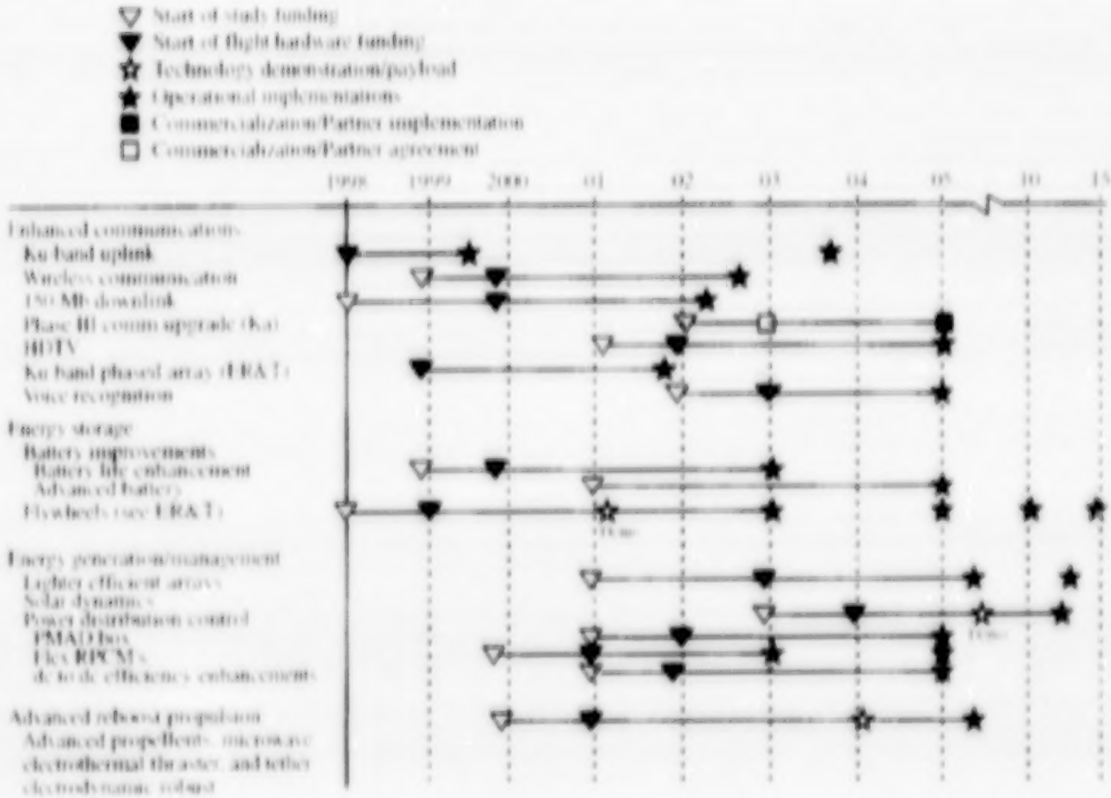


Figure 2.1-1. ISS systems, operations, and payload accommodations for schedule 1.

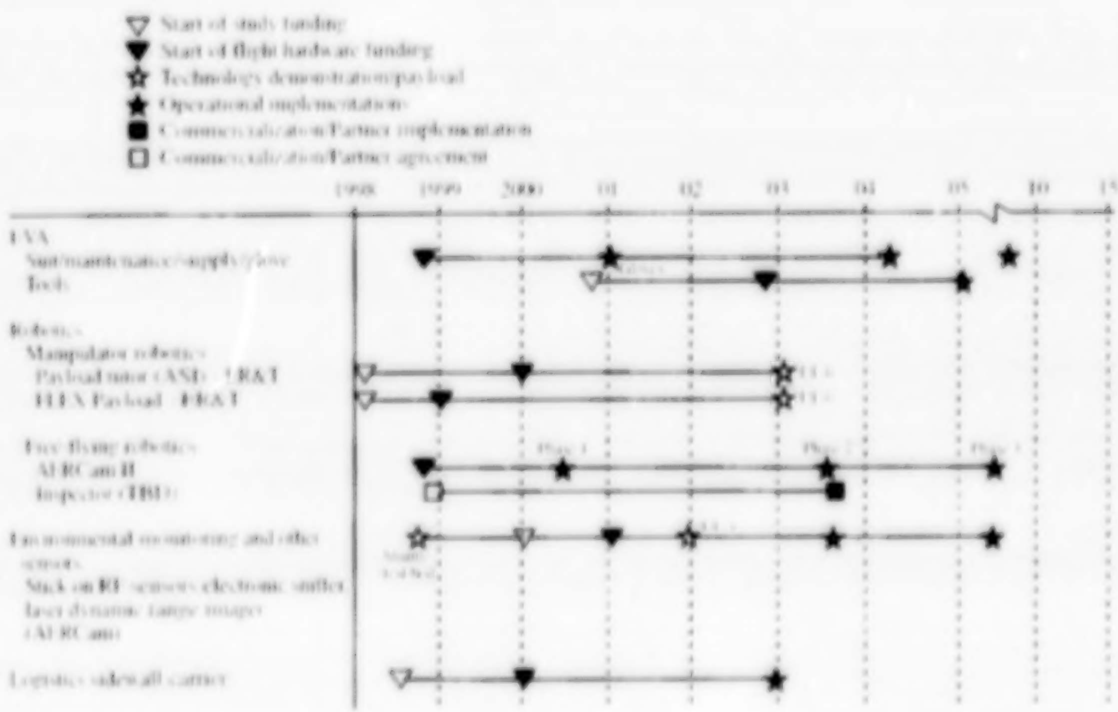
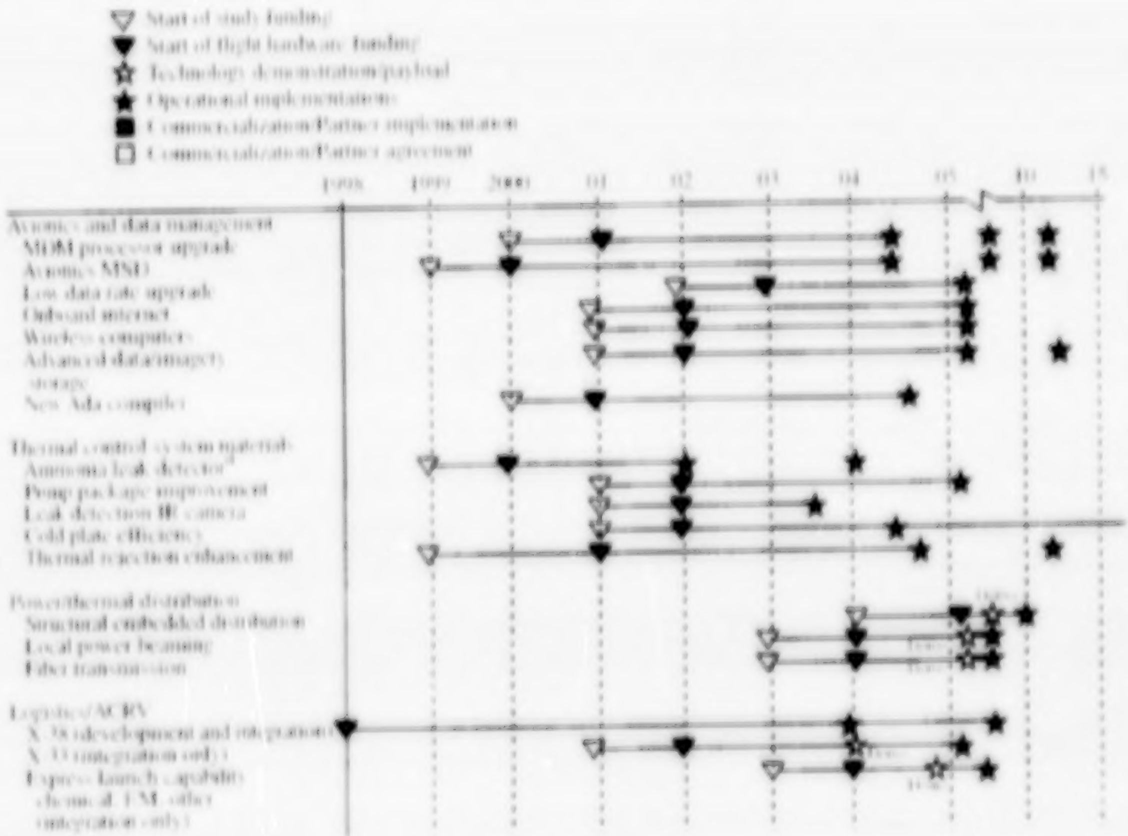


Figure 2.1-2. ISS systems, operations, and payload accommodations for schedule 2.



[a]Part of environment monitoring contaminant detector study

Figure 2.1-3. ISS systems, operations, and payload accommodations for schedule 3

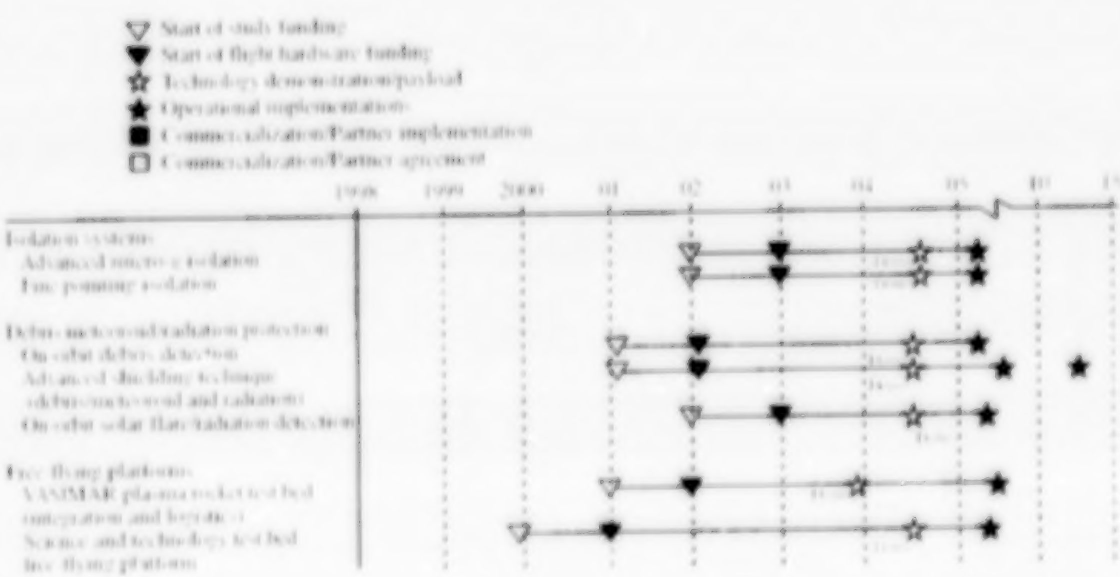


Figure 2.1-4. ISS systems, operations, and payload accommodations for schedule 4

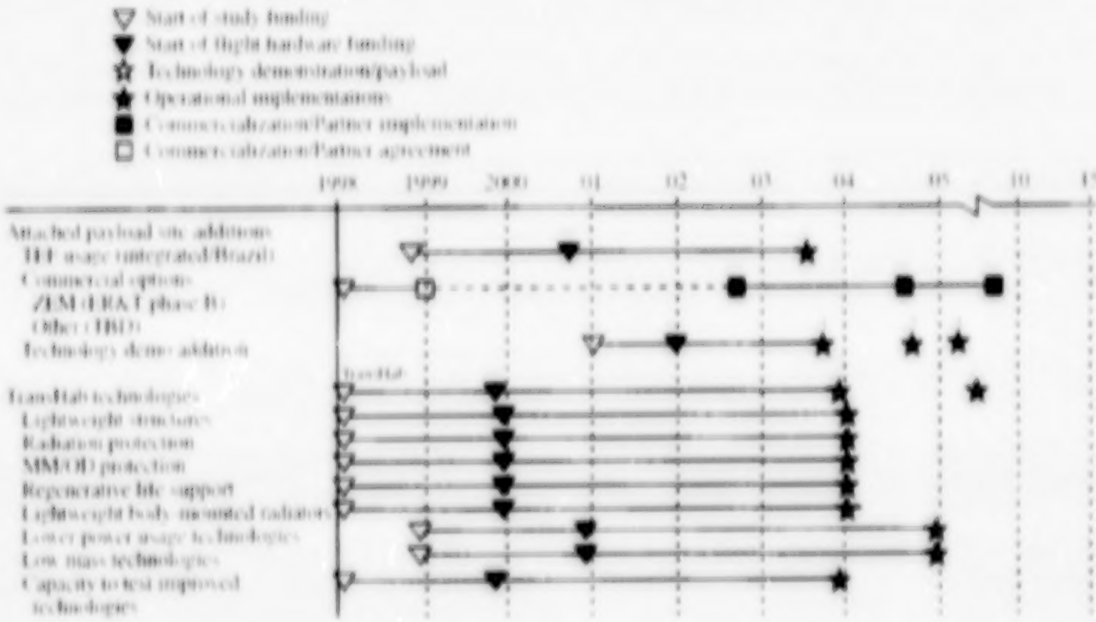


Figure 2.1-5. ISS systems, operations, and payload accommodations for schedule 5.

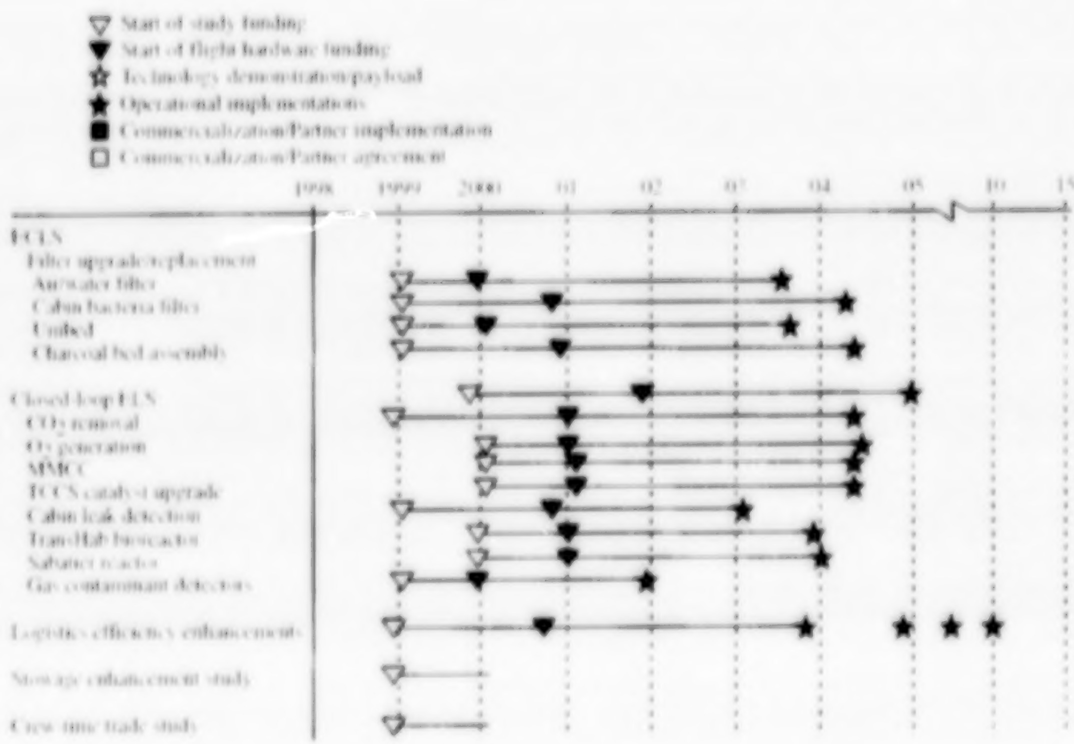


Figure 2.1-6. ISS systems, operations, and payload accommodations for schedule 6.

3. Proposed Research and Commercialization Activities

One of the primary goals of the ISS is to actively support commercialization opportunities to reduce the cost to develop and operate the ISS and to add or enhance its technical capability. The ISS program will address commercialization through three principal methods:

- Actively pursue agreements with commercial companies that are currently wanting to participate
- Based on a "Needs" list (such as P^3I), solicit agreements to bring these items into the station architecture and operations
- Actively solicit and review commercialization plans and opportunities from industry

Commercialization may be used to support ISS growth by enhancing either the research capability and/or the habitation capability of the ISS. These enhancements would provide additional resources and or facilities to expand the current capabilities.

Potential commercialization opportunities for implementation in the short term (1999–2002) include communications, ground operations, imagery, and pharmaceuticals. Potential commercialization opportunities for implementation in the long term (2003–2005) include transportation and logistics.

4. Advanced Research Opportunities

To be supplied (TBS)

5. Design Reference Missions for ISS Evolution

5.1. Introduction

Improvements in ISS systems and operations are being developed through the P^3I Working Group. ISS enhancements are also being planned to accommodate commercial applications and HEDS mission support. Synergistic evolution of the ISS requires coordination of P^3I technology development with the HEDS advanced mission accommodations and utilization and commercialization activities. The LaRC ISS Working Group is facilitating this coordination by developing and maintaining this ISS Evolution Data Book for NASA Headquarters, Code M. The design reference missions (DRM's) are being defined and analyzed to identify synergistic technology investments that can augment performance of the ISS to most cost-effectively support future HEDS, commercialization, and utilization efforts. These DRM's will be used to identify technology investment and commercialization opportunities for the ISS. Current DRM's include commercial TransHab utilization, application of P^3I technology road maps, accommodation of an advanced communications tower (ACT), accommodation of free flyers, satellite servicing, and utilization of a tether for ISS orbit maintenance. The set of DRM's will continually evolve as the ISS is assembled and operated.

The DRM's included in this section are preliminary drafts and do not represent any officially sanctioned path for ISS evolution. The DRM's represent current advanced concept studies for after ISS assembly complete utilization and enhancements. The depth, scope, and quantity of the DRM's will be enhanced in the coming year. The P^3I technology road maps have been included in section 2.1.2 so that other potential ISS enhancements can be used to assess impacts to future transportation architectures.

5.2. Implementation of Energy Storage Enhancement as a P^{3}I Technology

5.2.1. Description

TBS

5.2.2. ISS Enhancement Goal

The energy storage enhancement activity has the goal of inserting an enhanced energy storage option into the ISS electrical power system (EPS) in order to increase power available on the ISS and to reduce operational costs. The primary options currently under consideration are enhanced or advanced batteries and the use of mechanical flywheels. By increasing specific energy (Watts-hour/kilogram) and energy density (Watts-hour/liter) in the enhanced batteries, battery life will be extended, and resupply ORU mass and volume and crew time for maintenance changeouts will be reduced. The use of mechanical flywheels drastically reduces resupply and crew time requirements and has a potential added benefit of providing a portion of the ISS momentum management function.

5.2.3. Enhancement Specifications

5.2.3.1. Physical Description

Three enhanced energy storage options are currently being studied in the P^{3}I program.

Enhanced baseline battery (NiH_2): These enhancement options include a modification of the electrolyte concentration and two design modifications of the pressure vessel containment. These enhanced batteries are manufactured by Eagle-Picher Industries, Inc. The enhanced batteries offer modest increased energy storage capacity but require the least amount of development.

Advanced technology battery (i.e., lithium ion, lithium polymer): P^{3}I advanced technology batteries are all focused on lithium cells, with variations on the opposing electrode and electrolyte. The lithium polymer configuration of 3M, for example, uses a solid polymer foil as the electrolyte, which disperses and recombines during the charge-discharge cycles. This design has a significant safety advantage over other lithium batteries because there are no pressure vessels to contain nor leakage concerns. This technology area benefits from a diverse and aggressive development effort in the aerospace sector. Compared with the baseline ISS batteries, theoretical and demonstrated energy storage capacity of three to four times and energy density of over two times appear realistic but still require life-cycle testing.

Mechanical flywheels: The P^{3}I use of mechanical flywheels is in the form of the attitude control and energy storage experiment (ACESE), with the goal of protoflighting a replacement of the baseline battery/battery charge discharge unit (BCDU) ORU's during their first maintenance changeout. ACESE is an ORU box (comparable in size with the BCDU) that contains two identical counterrotating flywheels. The flywheel unit has rotors with an outside diameter of approximately 15 in., magnetic radial and axial bearings with conventional bearing backups, and a motor-generator unit. The total weight for the ACESE unit is 430 lb with margin, compared with the combined weight of 575 lb for the baseline battery/BCDU ORU's.

The functional description and primary assumptions are as follows:

Enhanced baseline battery (NiH_2): The design driver for the enhanced baseline batteries is to increase the specific energy capacity of the battery; thereby a lower depth of discharge (DOD) is allowed for the same mass of battery. Because the primary cell failure mechanism is cycling at a high DOD, reducing nominal DOD results in an increase in battery life.

Advanced technology battery (i.e., lithium ion, lithium polymer): Similar to the enhanced NiH_2 battery, the design driver is to increase the specific energy capacity of the battery. Two performance approaches are possible: use the increased energy storage ratings to decrease the mass and volume of the batteries on orbit or use the same mass and volume of advanced batteries to increase peak energy capability and to decrease nominal DOD. The primary assumptions for the insertion of advanced batteries are that they will be ready (mature) by the time the baseline batteries require changeout and their use will require minimal modification to the baseline electrical power system (EPS) design and control. Although indications are that the technology readiness level (TRL) of many of these batteries will allow their use, the high temperature operation of the lithium polymer battery raises questions about system modifications to accommodate them.

Mechanical flywheels: The motor is fed primary power during sunlight times and spins up the rotors to over 50000 rpm. During eclipse times, the rotor turns the generator to provide primary power. The ACESE unit is designed to provide the nominal energy storage for one battery/BCDU ORU. In addition, ACESE is designed to provide one-degree-of-freedom attitude control. The ACESE experiment is intended to provide the design path to using mechanical flywheels as an EPS enhancement. Mechanical flywheel energy storage is assumed to have orbital lifetimes that span through the ISS lifetime.

5.2.4. Interface Requirements

The interface requirements for the advanced batteries are given.

Enhanced baseline battery (NiH_2): All interfaces are the same (big advantage) as the baseline batteries except for a minor additional software interface for the single-pressure vessel (SPV) design. The SPV design will require some additional monitoring of critical cell operational parameters.

Advanced technology battery (i.e., lithium ion, lithium polymer): Potential negative impacts exist in the interface area for advanced batteries. For example, the lithium polymer design with the solid polymer has an operational temperature of 80 °C as opposed to baseline station batteries at around 0 °C. This temperature requirement would require a separate mounting structure than the other EPS components on the integrated equipment assembly (IEA). An integrated energy analysis would have to be done to determine thermal control interface requirements. The software interface would likely be designed to be a transparent change to ISS.

Mechanical flywheels: The existing IEA cold plate beneath the BCDU is sufficient for the ACESE ORU. The cold plate provides the structural and thermal interface. The power consumed by ACESE is less than the BCDU. Data service required is comparable with the current

photovoltaic control unit (PVCU) just as a battery for ISS.

5.2.5. Enhanced ISS Configuration Description

This section identifies any impact that a change made because of enhancement has on the ISS.

5.2.6. ISS Impacts

5.2.6.1. Installation

Enhanced baseline battery (NiH_2): No impact.

Advanced technology battery (*i.e.*, lithium ion, lithium polymer): No identified impact, although thermal requirements for some battery choices may complicate installation (i.e., separate cold plate, radiator).

Mechanical flywheels: No impact; the mechanical flywheels are designed as a "plug and play" unit, with similar handling characteristics of a BCDU.

5.2.6.2. Vehicle Configuration

5.2.6.2.1. Mass Properties

No impact.

5.2.6.2.2. Flight Attitude

No impact.

5.2.6.2.3. Control

No impact.

5.2.6.2.4. Orbital Lifetime

No impact.

5.2.6.3. Operations

5.2.6.3.1. Intravehicular Activity

No impact.

5.2.6.3.2. Extravehicular Activity

Enhanced baseline battery (NiH_2): Slight reduction in EVA due to improved reliability.

large savings of EVA because of extended lifetimes.

Mechanical flywheels: Potential large savings of EVA will happen because of extended lifetimes.

5.2.6.3.3. Ground Support Operations

No impact.

5.2.6.3.4. Visiting Vehicle Operations

No impact.

5.2.6.4. Utilization

5.2.6.4.1. Microgravity

No impact.

5.2.6.4.2. Payload Accommodations

No impact.

5.2.6.4.3. Payload Operations

No impact.

5.2.6.5. ISS Subsystem Impacts

5.2.6.5.1. Command and Data Handling

No impact.

5.2.6.5.2. Communications and Tracking

No impact.

5.2.6.5.3. Crew Systems

See section 5.2.6.3.2.

5.2.6.5.4. Environmental Control and Life Support Systems

No impact.

Enhanced baseline battery (NiH_2): No impact.

Advanced technology battery (i.e., lithium ion, lithium polymer): No impact.

Mechanical flywheels: If flywheels are substituted for battery/BCDU's, some of the guidance, navigation, and control (GN&C) functions will be shared with the EPS.

5.2.6.5.6. Power

See sections 5.2.3.1 and 5.2.3.2.

5.2.6.5.7. Propulsion

No impact.

5.2.6.5.8. Robotics

No impact.

5.2.6.5.9. Structures and Mechanisms

No impact.

5.2.6.5.10. Thermal Control

Enhanced baseline battery (NiH_2): No impact.

Advanced technology battery (i.e., lithium ion, lithium polymer): See "Advanced technology battery" in section 5.2.4.

Mechanical flywheels: No impact.

5.3.1. Description

The ISS, once operational, may provide the capability to service various visiting vehicles that are in a relatively similar orbit to the Station. Servicing would include changeout of payloads, replenishment of consumables, repair, and refurbishment operations. Information from the documents listed in the bibliography (section 5.3.7) was used to compile this section.

5.3.2. ISS Enhancement Goal

The goals of ISS free-flyer satellite servicing are as follows:

1. Provide enhanced science and manufacturing capabilities with free-flyer unique features: ISS-tended free-flying spacecraft will provide the experiment payload community with unique research capabilities such as a longer duration microgravity environment with minimal disturbances, additional flexibility of operations, enhanced pointing capability, altitude adjustment, and low contaminate levels around the free flyer (FF).

2. Provide ISS risk mitigation opportunities: In addition to science research capabilities, ISS-tended free flyers will be used to investigate risk mitigation technologies for ISS such as advanced propulsion and structures.

3. Reduce the Space Transportation System (STS) upmass and downmass for launch and landing requirements: Maintaining free-flying spacecraft from the ISS instead of returning them to Earth will provide enhanced ISS capability and reduce the upmass and downmass for the STS.

5.3.3. Enhancement Specifications

5.3.3.1. Physical Description

Unpressurized free flyers would be berthed to attached payload locations on the ISS truss (S3 and P3). Four attached payload sites are defined for S3 (fig. 5.3-1) and two for P3. However,

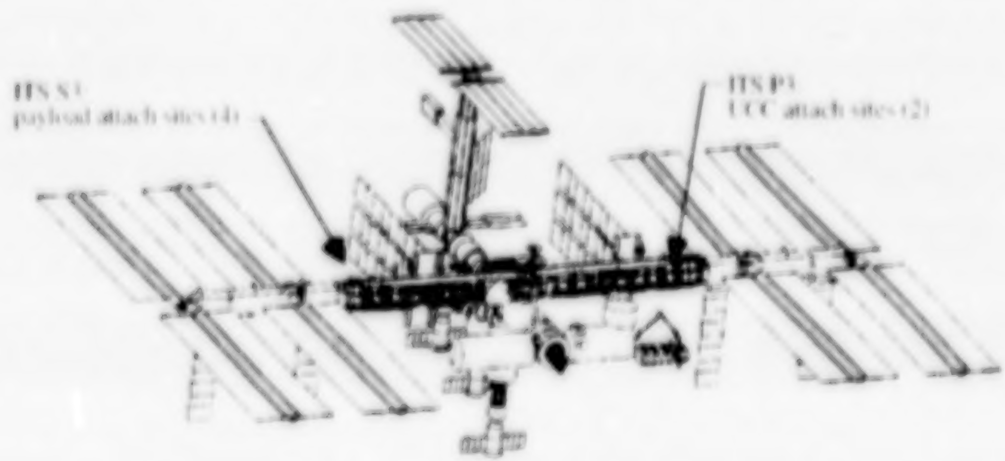


Figure 5.3-1 Attached payload sites for S3.

free-flyer servicing may include the Japanese experiment module (JEM) exposed facility (EF), the planned European attached facility, and additional sites on the truss.

ISS free-flyer satellite servicing would leverage the use of existing attached payload components: Station (EXPRESS) pallets, unpressurized logistics carriers (ULC), and the McDonnell Douglas SPACEHAB integrated cargo carrier (ICC). The EXPRESS pallets (fig. 5.3-2) and ULC's may be used for storing consumables and hardware for changeout. The ICC could be used to transport consumables and hardware on the STS (fig. 5.3-3).

Attached payload system components, such as the payload attachment system (PAS) passive mechanism, the umbilical mechanism assembly (UMA) interface, and EXPRESS pallet adapters (ExPA's), may also be incorporated into free-flyer designs. The PAS and UMA could be used on free flyers to allow berthing to an attached payload location (fig. 5.3-4). ExPA's (or similar hardware) may also be incorporated into the free-flyer designs to simplify changeout of payloads and consumables (fig. 5.3-5).

5.3.3.2. Functional Description and Assumptions

A free-flying spacecraft, after completing its initial mission, would move from its operational orbit to the ISS orbit. Consumables and hardware for changeout, previously delivered by the Shuttle, would be waiting at the ISS on an EXPRESS pallet or ULC. After the free flyer is maneuvered

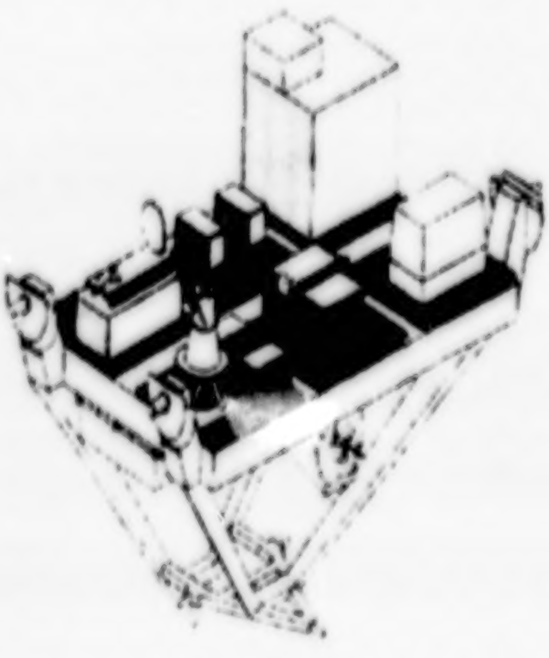


Figure 5.3-2. EXPRESS pallet.

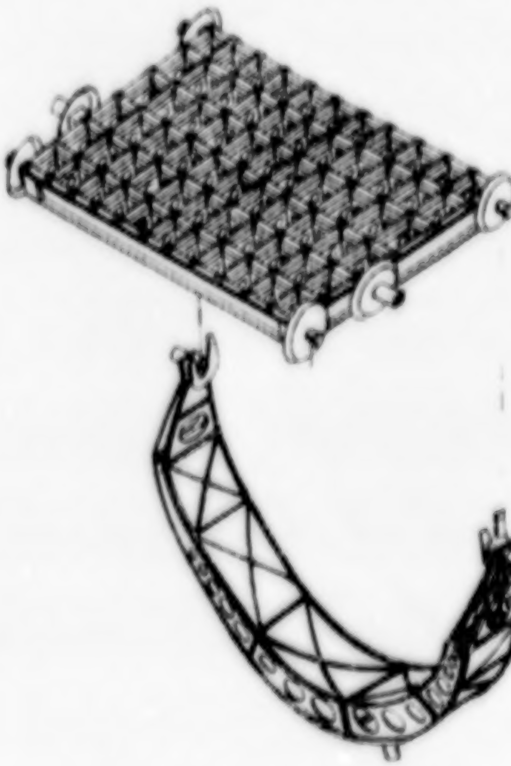


Figure 5.3-3. SPACEHAB ICC.

Figure 5.3-4. PAS/UMA.

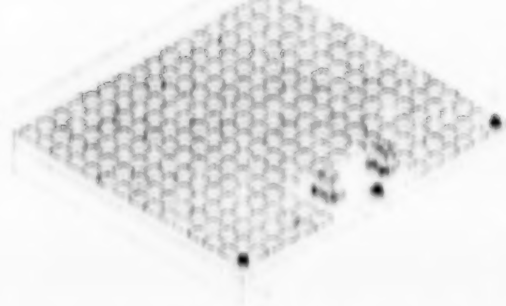


Figure 5.3-5. ExPA.

to the appropriate area, the Space Station remote manipulator system (SSRMS) would be used to berth the free flyer to the ISS attached payload location. The ISS crew would use the SSRMS to exchange payloads, systems, and consumable containers. A checkout of the free flyer would be conducted prior to release from ISS. The SSRMS would then release the free flyer, which would return to its operational orbit.

The following assumptions were made:

- The free-flyer servicing capability will be configured, deployed, and utilized after ISS assembly complete (AC).
- A free-flying spacecraft will contain a propulsion system to maneuver from its operational orbit to the ISS orbit.
- A free-flying spacecraft will be capable of automated and onboard (ISS) control for proximity operations.
- The free-flying spacecraft will be berthed at a designated attached payload location where servicing activities will be conducted.
- The ISS will provide an additional attached payload location for stowage of free-flyer consumables and experiment hardware.
- Free-flyer design will allow maximum use of SSRMS for servicing activities and will only require EVA for contingency operations.

5.3.4. Interface Requirements

The external free-flyer servicing requires two attached payload locations: one for berthing of the spacecraft and the other for storage of an EXPRESS pallet or ULC containing the consumables, and equipment for changeout. The spacecraft, consumables, and equipment will provide SSRMS-compatible grapple fixtures to support servicing activities.

The internal free-flyer servicing will not require direct internal interfaces with the ISS. However, free flyers will be required to be compatible with the ISS communications system for control during proximity operations.

The enhanced ISS configuration will be the same as the baseline ISS configuration. The free-flyer servicing capability would utilize existing attached payload accommodations, and the hardware would fit within the associated envelopes.

5.3.6. ISS Impacts

5.3.6.1. Installation

Consumables and hardware for changeout, attached to an EXPRESS pallet or ULC, would be delivered by the Shuttle, and berthed to an attached payload location on the ISS, by using the SSRMS. Free flyers would rendezvous and be berthed to ISS as described in section 5.3.3.2.

5.3.6.2. Vehicle Configuration

5.3.6.2.1. Mass Properties

A free flyer will have a mass of approximately TBD kg. The EXPRESS pallet or ULC containing the consumables and equipment for changeout will have a mass of approximately TBD kg.

5.3.6.2.2. Flight Attitude

TBD

5.3.6.2.3. Control

TBD

5.3.6.2.4. Orbital Lifetime

TBD

5.3.6.3. Operations

5.3.6.3.1. Intravehicular Activity

Intravehicular activity (IVA) would be required for control of free flyers during proximity operations and to control the SSRMS in the berthing of a spacecraft to an attached payload site.

5.3.6.3.2. Extravehicular Activity

EVA would be required only in situations where the SSRMS cannot be used and in situations where the SSRMS has failed.

Ground control would initiate the free flyer to move from its operational orbit to the ISS orbit. Control would be handed over to ISS IVA crews for proximity operations.

5.3.6.3.4. Visiting Vehicle Operations

TBD

5.3.6.4. Utilization

5.3.6.4.1. Microgravity

Free-flyer servicing activities (berthing, consumable replenishment, hardware changeout) will be limited to defined time periods outside the ISS "quiescent" period to prevent disturbance of the ISS microgravity environment.

5.3.6.4.2. Payload Accommodations

ISS-attached payload accommodations would be used to implement the servicing capability; however, the loss of payload accommodations on the ISS would be offset by the additional payload accommodations provided by the free flyers. The associated advantages (longer duration microgravity environment, flexibility of operations, enhanced pointing capability, altitude adjustment, and low contaminate levels) of the free flyers would also offset the loss of attached payload accommodations.

5.3.6.4.3. Payload Operations

TBD

5.3.6.5. ISS Subsystem Impacts

5.3.6.5.1. Command and Data Handling

The free flyer, while berthed to an attached payload location, may use the ISS data interface or its own free-flyer command and data handling system.

5.3.6.5.2. Communications and Tracking

The ISS communications subsystem would be used for controlling free-flying spacecraft during proximity and berthing operations.

5.3.6.5.3. Crew Systems

Free-flyer servicing capability will use existing crew systems, such as EVA tools.

No impact.

5.3.6.5.5. Guidance, Navigation, and Control

No impact.

5.3.6.5.6. Power

No impact.

5.3.6.5.7. Propulsion

TBD

5.3.6.5.8. Robotics

The SSRMS would be used to berth the free flyer to an ISS-attached payload location and also to release it. The ISS crew would also use the SSRMS to exchange payloads, systems, and consumable containers.

5.3.6.5.9. Structures and Mechanisms

TBD

5.3.6.5.10. Thermal Control

No impact.

5.3.7. Bibliography

Gay, Clarence: Attached Payload Interface Requirements Document. International Space Station Program, SSP 57003, NASA Johnson Space Center, Mar. 15, 1999.

Primm, Lowell E., Jr.; and Cook, G.: EXPRESS Pallet System Development Specification. International Space Station Program, SSP 52055, NASA Johnson Space Center, June 29, 1998.

Sampson, Margarita; and Derevenko, Vladimir: Interface Definition Document (IDD) for International Space Station (ISS) Visiting Vehicles (VVs). International Space Station Program Office, SSP 50235, NASA Johnson Space Center, Jan. 25, 1999.

5.4.1. Description

The ISS ACT is an advanced communications concept comprised of locating sets of Ka-band PAA's on top an ~50-ft deployable mast structure, which is attached to the top of the centrifuge accommodation module (CAM). (See fig. 5.4-1.) The ACT will provide advanced communications capabilities for ISS payloads desiring dedicated high return link data rates and near continuous coverage with either advanced TDRSS satellites (H, I, and J) or a commercial telecommunications satellite constellation network. Information from the documents listed in the bibliography (section 5.4.7) was used to compile this section.

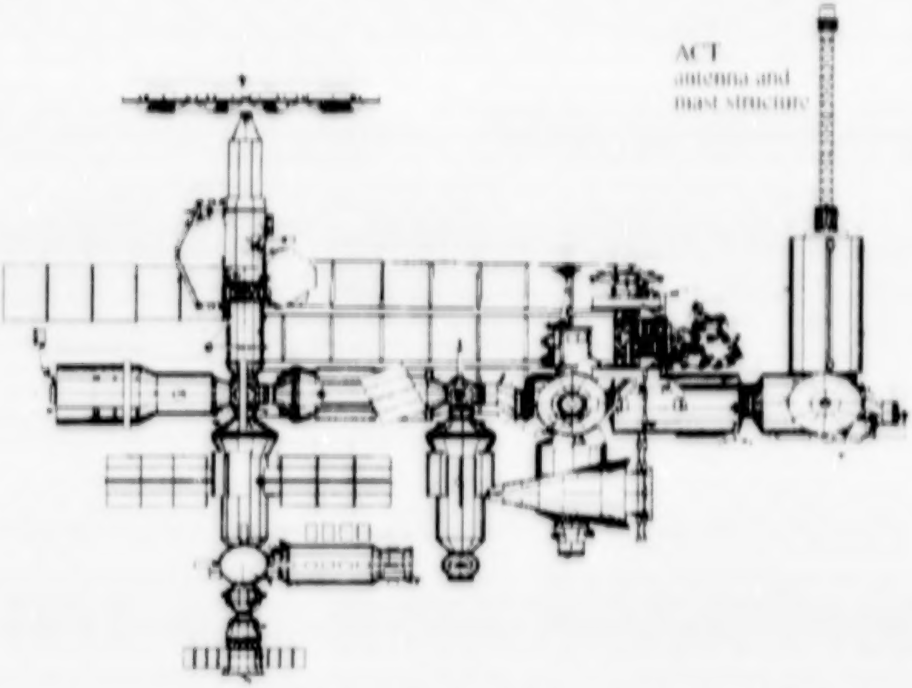


Figure 5.4-1. ACT on top of CAM

5.4.2. ISS Enhancement Goal

The goal of the ACT is to provide nearly 100 percent of communications coverage with either the advanced TDRSS Network (TDRSS H, I, and J) of communications satellites, or a commercial telecommunications satellite network (e.g., Celestri and Teledesic).

In response to an anticipated need by the payload community for a dedicated real-time return link of experiment data, ACT will provide the payload community with a higher bandwidth dedicated connection of telemetry data capability (>100 Mbps) to facilitate experiments. Taking advantage of newer technologies in the communications industry, ACT will provide a platform to allow communications with generations of communications satellites. Initially, incorporating ACT will require modifications or additions to the design of the CAM to include provisions (scars) to mount to the tower; support power, data, and control bus (1553) operations with the PAA's; and to provide a high bandwidth data interface connection to ISS payloads. Some early provisions for ISS resources (power and data buses) and software additions must also be targeted in the preliminary arrangement to accommodate the ACT.

5.4.3.1. Physical Description

5.4.3.1.1. Self-Deployment Mast Structure

The ACT tower section is comprised of an ≈50-ft self-deployable articulated mast (manufactured by AEC-Able Engineering Company, Inc.) that is attached to the top of the CAM. Once the ACT is maneuvered and attached to the CAM via EVA and robotic arms, the articulated mast self-deploys from the canister to the full extension of ≈50 ft. Table 5.4-1 shows the physical details of the mast. This mast portion of the ACT, defined as the Able deployable articulated mast (ADAM), will extend to greater than 25 times its stowed length. The deployed mast is an internally preloaded truss exhibiting near-linear structural behavior and is housed within a canister that is bolted to the CAM. The canister will be a redesign of a previously successful configuration to be used on a future Shuttle mission (Shuttle radar topography mission (SRTM)); thereby, the mass is reduced as required through the removal of unnecessary structure while maintaining full functionality. The primary mechanical interface will be relocated to a single mounting ring. The canister shells, rings, tip plate, base plate, gussets, brackets, stiffeners, and mounting pads will be deleted or redesigned as required to meet ISS launch loads and interface specifications. (See fig. 6.4-2.)

Table 5.4-1. Physical Details of ISS ACT

Geometry:	
Nominal mast diameter, m (in.)	1.12 (44.123)
Nominal bay width, cm (in.)	79.25 (31.200)
Nominal bay length, cm (in.)	69.75 (27.462)
Number of bays	22
Mast stroke, m (in.)	14.7 (576)
Canister diameter estimate, m (in.)	1.32 (52)
Canister length estimate, m (in.)	2.26 (89)
Mass:	
Mast mass estimate (with utilities), kg (lbm)	160 (352)
Canister mass estimate, kg (lbm)	≤500 (1100)
Stiffness:	
EI, MN-m^2 (lbf-in^2)	13 (4.7×10^9)
GA, MN (lbf)	0.49 (1.1×10^4)
GJ, MN-m^2 (lbf-in^2)	0.15 (5.3×10^7)
Fixed-free first bending mode, Hz	0.68
Fixed-free first torsion mode, Hz	1.9
Strength:	
Moment strength, M_{CT}, N-M (in-lbf)	8140 (72 000)
Shear strength, V_{CT}, N (lbf)	400 (90)
Torsional strength, T_{CT}, N-m (in-lbf)	305 (2700)
Stability:	
Bending stability (rotation) (0.1 N-m), arc sec (deg)	±0.02 (±6.0×10^{-6})
Bending stability (translation) (0.1 N-m), μm (in.)	±2.5 (±0.100)
Torsion stability (0.1 N-m), arc sec (deg)	±4.9 (±0.0014)
Axial stability, μm/N (in/lbf)	±0.4 (±0.75)

Figure 5.4-2. ACT deployable articulated mast canister.

The launch restraint, stack advance, stack restraint, root stiffness, and deployment systems will be essentially the same as SRTM. In addition, the ACT canister will be approximately 68 cm shorter than the SRTM canister because of the shorter mast stroke (16 m versus 60 m). The ACT mast system is designed to deploy, retract, and redeploy on orbit if required.

Prior to deployment of the mast, the ACT must first be connected to the CAM through a series of bulkhead connectors to connect power, control, and data interfaces to the inside of the CAM; then it is physically bolted to the CAM using 16 0.5-in. bolts. EVA is expected to be utilized along with the Shuttle's robotic arm for ACT removal from the Shuttle bay and placement onto the CAM. When guy wires are used, four additional connections are made to mount these cables or wires to the structure of the CAM for support.

5.4.3.1.2. Phased Array Antenna Complex

This antenna configuration, which utilizes multiple PAA's for maximum coverage to the communications satellites, will be configured to provide >±120° coverage (nonoptimized) about the elevation axis and ±70° about the azimuth axis. Each PAA will be a multielement (>512) array of transmission and receive elements designed onto a platform complete with electronics, power, and data interfaces. (See fig. 5.4-3.) Each antenna will be multiplexed and combined with the others to complete the PAA complex. A combined electronics box (CEB) will be used for controlling the antenna array functions, multiplexing the antenna signals together, coordinating data and commands sent from and to the ISS interfaces, and providing the proper signal format to communicate with the satellites.

5.4.3.2. Functional Description and Assumptions

Before the ACT mast begins to self-deploy, the PAA assembly must be placed onto the mast mounting structure, and all interface connections must be completed. At the fully deployed range, the PAA complex will be >70 ft above the ISS truss structure. Through control electronics and software, these PAA's will be electronically steered to maintain optimum pointing to the communications satellites. When one of the antennas is close to being out of the coverage range to a particular communications satellite, a switchover to another antenna will occur (if possible) to continue communications coverage with that satellite. Similarly, if a communications satellite is

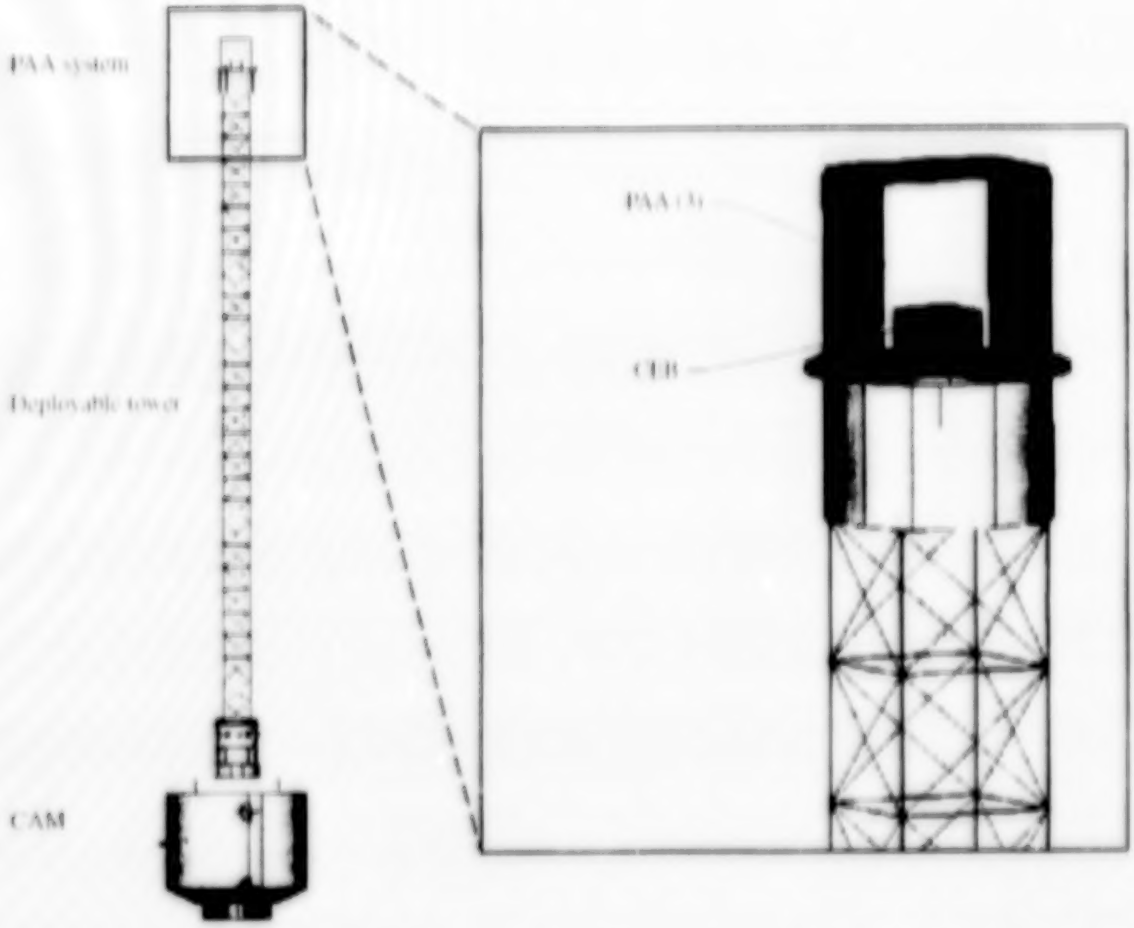


Figure 5.4-3. Phased array antenna complex.

about to go out of range, a switchover to another selection may be necessary to pick up coverage to another satellite.

Connections to the payload high rate data link (HRDL) and automated payload switch (APS) interfaces exist through connections within the CAM to provide the capability for payloads to send data to the ACT PAA complex for data return to Earth. Payload software (via payload MDM) will be responsible for coordinating and controlling the data rates. Control bus connections (via 1553) are available to the PAA complex to allow for the control and status of the system.

The assumptions are as follows:

- The ACT will be configured, deployed, and utilized after ISS AC.
- The CAM design can be modified to include scars that will accommodate the ACT at a later date.
- The ISS has sufficient power reserve at AC to meet the needs of the ACT.
- The payload MDM will provide command, control, and coordination of status with the PAA assembly.

- The CAM has sufficient resources and interface connections to meet the needs of the ACT.

- The command and control (C&C) MDM and/or payload MDM software will include the capability to initialize pointing control of the PAA steerable beams and will contain information regarding satellite locations.

5.4.4. Interface Requirements

The ACT requires external interface connections to occur right at the CAM zenith end cap bulkhead plate. These interface connections will be responsible for providing power to the PAA's, for providing a 1553 data interface between the PAA's and control software located within ISS (payload MDM), and for providing fiber optic data lines for both forward and return data link paths. There may also be four attachment points on the CAM to accommodate guy wires for the tower structure when it is fully deployed.

The CAM will need to provide the following internal interfaces with the ISS to accommodate the ACT:

- Provide a switched connection to the ISS power bus.

- Provide a 1553 interface connection that has an active path back to the C&C MDM and the payload MDM.

- Provide a fiber-optic interface with the payload HRDL system for a return link path.

- Provide an interface to accept forward link data sent by the ground center and transfer these data to payload MDM and/or C&C MDM.

5.4.5. Enhance ISS Configuration Description

As discussed in section 5.4.1, ACT will provide a platform of state-of-the art technology communications which can be used to provide near continuous coverage to either the advanced TDRSS satellite network (H, I, and J), or to a particular commercial telecommunications satellite constellation network. The study to include ACT is based upon an AC configuration of the ISS, with attempts to identify those design changes to ISS hardware and software that would be necessary for ACT to succeed. At most, the CAM will need most of the design additions to accommodate the tower structure and the PAA network and to interface with ISS power, control, and data buses. Internal connections to the HRDL and APS may need some rerouting to provide the payload connectivity with the ACT link, and some system software will need modifications or additions for controlling the PAA's and configuring the connections to the satellites.

5.4.5.1. Communications Coverage

The ACT will improve the coverage of return data from the ISS. As designed, the ISS initially will provide Ku-band return rates of 50 Mbps (43.2 Mbps true data) at AC. Expected enhancements to reach 150 Mbps are planned. Table 5.4-2 shows the estimated TDRSS coverage of Ku-band communications by assembly flights; the best coverage is about 72 to 86 percent to a three-satellite TDRSS network. Software "keep-out" zones will further degrade the coverage available, maybe as much as another 10 to 15 percent. These keep-out zones are necessary to avoid radiation contamination of EVA astronauts and certain modules or systems. The ACT will

Table 5.4-2. Typical TDRSS Coverage for ISS Ku-Band by Flights

Analysis data taken from JSC-Lockheed Martin communications coverage study performed on a DAC 5 model of the ISS with zero beta angle on the solar arrays and an LVLH attitude mode

Ku-band coverage by flight	Two TDRS coverage, percent	Two TDRS coverage with Shuttle, percent	Three TDRS coverage, percent (a)	Three TDRS coverage with Shuttle, percent
7A	51.1	46.5	62.7	57.9
12A	50.1	29.1	66.6	36.8
1E	68.1	61.5	86.3	72.5

[a]Compare this coverage with total coverage of TDRS H, I, and J in tables 5.4-3.

provide an enhanced communications coverage approaching 100 percent when utilized with either advanced TDRSS (H, I, and J) or a commercial telecommunications satellite network.

5.4.5.1.1. Nonoptimized coverage

Although a multiplexed combination of three PAA steerable beamwidths could conceivably provide ±160° of electronically steerable coverage in the elevation (EL) direction (fig. 5.4-4), the analysis was performed with an elevation range of only −120° to +120°. By selecting this range, most of the ISS structure was outside the radiating zone of the ACT. This range provides a keep-out zone that is even larger than the planned ISS gimbal "masking" approach. To truly optimize the coverage analyses, the elevation range could be increased to enhance coverage to the satellites.

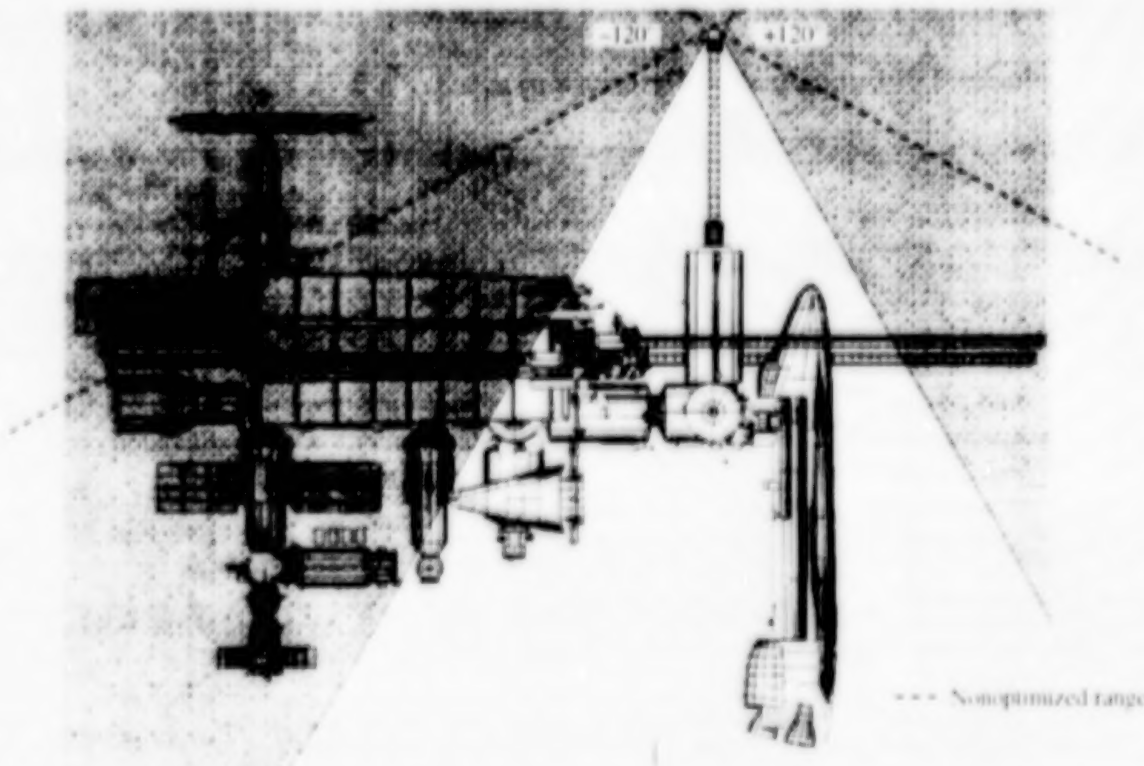


Figure 5.4-4. Elevation coverage range for all three antennas.

Based on selection and design criteria of the PAA complex (for purposes of saving mass and power), it is feasible to reach maximum coverage of 100 percent continuously. Tables 5.4-3 and 5.4-4 provide calculated coverage to both of these networks, based upon a 1- to 3-day analysis after AC. Analyses were performed using the Dynamic Engineering Communications Analysis Testbed (DECAT) software, which is widely used by the ISS Program Engineering Analysis Group at JSC. Use of DECAT was selected based upon a proven and reliable communications analysis capability at JSC to assess comparisons of the ACT coverage against current TDRSS coverage estimates using the same analysis tools. This assessment will help validate the coverage predictions while using the same ISS model (DAC6) to perform calculations.

Table 5.4-3. ACT Coverage to TDRSS (H, I, and J) at AC

Analysis	TDRS H coverage, percent (a)	TDRS I coverage, percent (a)	TDRS J coverage, percent (a)	Total theoretical coverage, percent (a)	Total coverage for full PAA AZ, percent (b)	Total coverage for degraded PAA AZ, percent (c)
Day 1	43.75	44.75	44.0	100	98	87
Day 2	43.4	45.6	44.1	100	98	87
Day 3	44.1	43.8	43.9	100	98	88
Day 4	43.9	44.2	44.2	100	98	88

[a]Total coverage calculated based on theoretical capability provides more than hemispherical coverage to ACT PAA's to show that if given this coverage at this tower location, 100 percent communications can be achieved; however, because PAA's at best can give ±70° in AZ steerable range, compare this coverage with "real" capability analyses.

[b]Utilization of full PAA AZ steerable range is realized; EL range is nonoptimized.

[c]Utilization of a slightly degraded PAA AZ steerable range is utilized to show the drop-off in coverage; EL range is nonoptimized.

Table 5.4-4. ACT Coverage to Commercial Telecommunications Network at AC

[Simulated Celestri/Teledesic partial constellation]

Satellite	Conditional coverage,[a] percent	Satellite	Conditional coverage,[a] percent
Plane 1—satellite 1–3	7.64	Plane 1—satellite 4–6	7.50
Plane 2—satellite 1–3	6.25	Plane 2—satellite 4–6	6.67
Plane 3—satellite 1–3	6.25	Plane 3—satellite 4–6	5.83
Plane 4—satellite 1–3	6.94	Plane 4—satellite 4–6	7.08
Plane 5—satellite 1–3	8.61	Plane 5—satellite 4–6	9.03
Plane 6—satellite 1–3	9.44	Plane 6—satellite 4–6	9.10
Plane 7—satellite 1–3	7.08	Plane 7—satellite 4–6	7.92
Plane 8—satellite 1–3	6.39	Plane 8—satellite 4–6	5.97
Plane 9—satellite 1–3	6.25	Plane 9—satellite 4–6	5.28
Plane 10—satellite 1–3	6.81	Plane 10—satellite 4–6	6.53

[a]AZ = −70° to +70°, EL = −120° to +120°.

5.4.5.1.2. Analysis Assumptions

Loss of signal (LOS) coverage to each TDRS satellite assuming PAA conditional coverage plus assuming H, I, and J are colocated where original TDRS satellites are located (41°W, 171°W, and 275°W longitudes, respectively). The following assumptions are made:

1. Proper handoff from one TDRS satellite to another is accomplished. Theoretical PAA antenna range used is $-90° < AZ < 90°$ and $-130° < EL < 130°$, where zenith direction is 0.0° EL and the velocity vector direction is 0° AZ.

2. Proper handoff from one TDRS satellite to another is accomplished. PAA antenna range is $-70° < AZ < 70°$ and $-130° < EL < 130°$, where zenith direction is 0.0° EL and the velocity vector direction is 0° AZ.

3. Proper handoff from one TDRS satellite to another is accomplished. PAA antenna range is $-60° < AZ < 60°$ and $-130° < EL < 130°$, where zenith direction is 0.0° EL and the velocity vector is 0° AZ.

5.4.5.1.3. Constellation Assumptions

The assumptions for the constellation are as follows:

- Analysis conducted with 72 satellites, 6 each equally spaced in 12 different planes

  Epoch date of January 1, 2003; simulation time of 1 day

  Near circular orbit; altitude of 1400 km; 90° inclination

  30° plane spacing between ascending node longitudes

  In-plane satellites separated by 60° (argument of perigee)

  Each plane shifts argument of perigee for each satellite by 15° to provide a spread coverage similar to a typical network

  Utilized satellite data for Celestri, specifically parameters for altitude, antennas, frequency, etc.

- Conditional coverage assumes the following PAA look angles from zenith boresight (EL = 0.0°):

  Azimuth range from −70° to +70°

  Elevation range from −120° to +120°

5.4.6. ISS Impacts

5.4.6.1. Installation

The ACT will be assembled on top of the CAM on orbit using EVA and robotic arms. First, the mast structure will be connected and placed on top of the CAM, followed by placement of the PAA platform on top of the mast prior to deployment. In both cases, hooking up bulkhead interface connections before final assembly on orbit will be necessary. Figure 5.4-5 shows a representative view of the mast. Further kinematic, obstruction, and reach analyses need to be done to show that the Shuttle RMS can reach the top of the CAM to place the ACT canister and PAA complex.

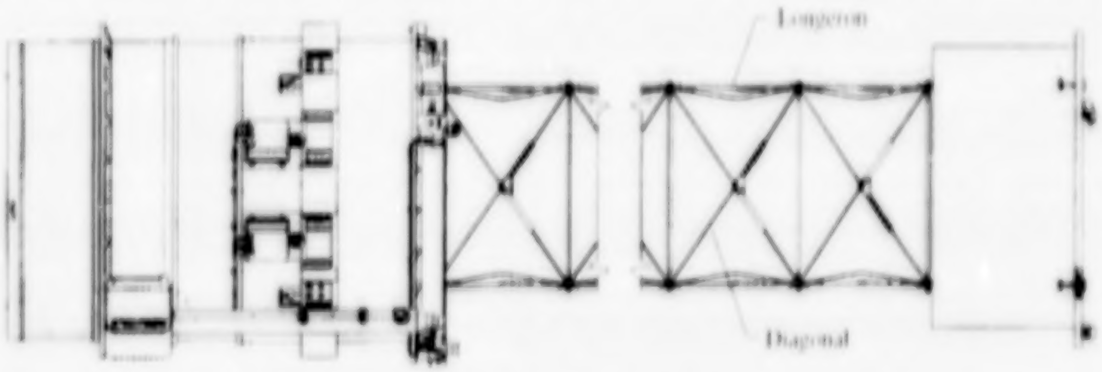


Figure 5.4-5. Tower canister and deployed mast

5.4.6.2. Vehicle Configuration

5.4.6.2.1. Mass Properties

The deployable articulated mast and canister will have a mass of approximately 600 kg. (See table 5.4-1.) The PAA platform will have a mass of approximately 200 kg. The power, control, and data interface cables will have a mass of approximately 60 kg.

5.4.6.2.2. Flight Attitude

A slight shift in ISS attitude may occur because of the addition of the ACT and its structural and mass properties. Additional studies will have to be conducted to verify that no major changes occur.

5.4.6.2.3. Control

A slight change in ISS control may occur because of the addition of the ACT and its structural and mass properties. Additional studies will have to be conducted to verify that no major changes occur here.

5.4.6.2.4. Orbital Lifetime

The same effects should be studied as presented in sections 5.4.6.2.2 and 5.4.6.2.3.

5.4.6.3. Operations

5.4.6.3.1. Intravehicular Activity

IVA may be needed to connect interface cables from inside the CAM to the top bulkhead connectors.

5.4.6.3.2. Extravehicular Activity

EVA will be required for mounting both the mast structure (nondeployed) and the PAA complex platform on top of the CAM, as well as connecting the interface bulkhead connections with the cables.

5.4.6.3.3. Ground Support Operations

TBD

5.4.6.3.4. Visiting Vehicle Operations

The impact of visiting vehicles must be studied to determine the structural loads and excitation modes during vehicle docking and berthing. Currently this study has not been performed.

5.4.6.4. Utilization

5.4.6.4.1. Microgravity

TBD

5.4.6.4.2. Payload Accommodations

Further investigations and studies may reveal that the ACT can accommodate other mounted instruments such as cameras, small stellar-looking payloads, material exposure structures, and structural characterization experiments. However, additional or new communications links might be necessary if the interfaces do not exist.

5.4.6.4.3. Payload Operations

Modifications most likely will be required to the Payload MDM software to facilitate control of sending payload data to the ACT data interface, as well as potential changes to payload ground control software and monitoring. Matters to consider carefully are control of the payloads with the new forward link capability of the ACT and how command data encryption and control would actually occur.

5.4.6.5. ISS Subsystem Impacts

5.4.6.5.1. Command and Data Handling

The command and data handling (C&DH) subsystem may require modification of the payload MDM software, as well as the addition of pointing control software to steer the beams of the PAA's during orbit.

5.4.6.5.2. Communications and Tracking

Enhanced communications reaching near 100 percent coverage to either the advanced TDRSS network or a particular commercial telecommunications satellite constellation can be achieved. ACT will provide the payload community with ~143 Mbps of return link bandwidth, and a potential of >1.5 Mbps of forward link communications. Investigations of the effect of additional blockage to the existing S-band and Ku-band systems need to be made because of the addition of the ACT. Some additional blockage may be expected to occur, but if the ACT provides much greater data transfer capability, maybe the existing Ku-band system can be used as a backup.

Because the ACT has electronically steerable PAA's, software will have to maintain a list of known satellite locations (in the case of TDRSS H, I, and J or commercial satellite networks) to properly steer the antenna beams during orbit.

5.4.6.5.3. Crew Systems

See the descriptions in sections 5.4.6.3.1 and 5.4.6.3.2.

5.4.6.5.4. Environmental Control and Life Support Systems

No impact.

5.4.6.5.5. Guidance, Navigation, and Control

If the ACT is used to communicate with commercial telecommunications satellites (non-NASA satellites), it may be necessary for the GN&C system to receive a data set of satellite locations, but at present this does not seem to be necessary. The "locations" of such satellites should exist within any software that may affect operations of the communications system.

5.4.6.5.6. Power

The ISS power subsystem will need to provide reserve power to the ACT and PAA platform. Power range may be from 575 to 1725 W.

5.4.6.5.7. Propulsion

At present the ACT has no effects on the ISS propulsion system, but the tower could possibly be used to augment roll control of the ISS by adding ORU thruster pods to the structure. A detailed study will have to take place to verify this capability.

5.4.6.5.8. Robotics

The SSRMS may be needed to remove the ACT assembly and PAA platform from the bay of the delivering vehicle.

5.4.6.5.9. Structures and Mechanisms

A redesign of the CAM zenith plate will be necessary to include bulkhead connections for ACT power, payload data, and control bus interfaces. The zenith side of the CAM must incorporate changes to add mounting hardware for the ACT structure, as well as a potential use of guy wires to stabilize the deployed configuration.

5.4.6.5.10. Thermal Control

TBD

5.4.6.6. Concluding Remarks

The ACT design approach and conditional analyses show that near-continuous communications coverage can occur by adding a deployable tower and state-of-the-art PAA's on top of the CAM. Table 5.4-3 indicates an increase in coverage to TDRSS satellites (H, I, and J) above what is already planned by the current ISS communications systems strategy at AC. Further, by utilizing access to a constellation[1] of commercial telecommunications satellites, it is conceivably possible to achieve near 100 percent coverage for a capable data return link from the ISS to any number of ground stations. Utilization of a commercial satellite constellation allows for the telemetry data for payload experiments to be "addressed" to reach a particular ground segment. The need to bring data to a focal point (i.e., WSGS in the case of TDRSS) before routing may no longer be necessary. True desktop computer access by individual PI's to their experiments in real time may be achievable.

Further analyses and design implementation studies and optimizations are needed to carefully determine the effects to both the current ISS communications capability and the design modifications to the CAM (and ISS (TBD)) that would be necessary to implement the ACT approach.

[1] By utilizing characteristics of a Celestri-like telecommunications constellation and by utilizing only 72 of a planned network of 288 satellites or more, table 5.4-4 indicates results from analyses showing coverage of approximately 94 percent. It seems indicative that a fully functional commercial telecommunications constellation, coupled with PAA optimization and operational planning, could provide payloads with full-time, real-time access to experimental data at data bandwidths greater than 100 Mbps.

5.4.7. Bibliography

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5.5. TransHab on ISS

5.5.1. Description

TransHab (TH) has been proposed as a transportation vehicle habitat for the Mars mission. The TH will be an inflatable, pressurized structure that will serve as the crew living and working quarters during the mission. This module has been proposed to add pressurized volume to the ISS.

5.5.2. ISS Enhancement Goal

The goal of using the TH is to provide additional volume for crew and research facilities. The TH could also be used as a reentry vehicle for the return of crew, products, and/or wastes from station activities. An aerobrake and heatshield will have to be added to the TH to facilitate its use as a reentry vehicle.

5.5.3. Enhancement Specifications

5.5.3.1. Physical Description

The TH is composed of two main elements—the shell and the core as shown in figures 5.5-1 through 5.5-4. The shell is a laminate of air bladders, structural webbing, thermal insulation, and impact shielding. The core contains the main structures, avionics, and ECLSS components. The TH is 27 ft in diameter and 40 ft in total length when fully inflated.

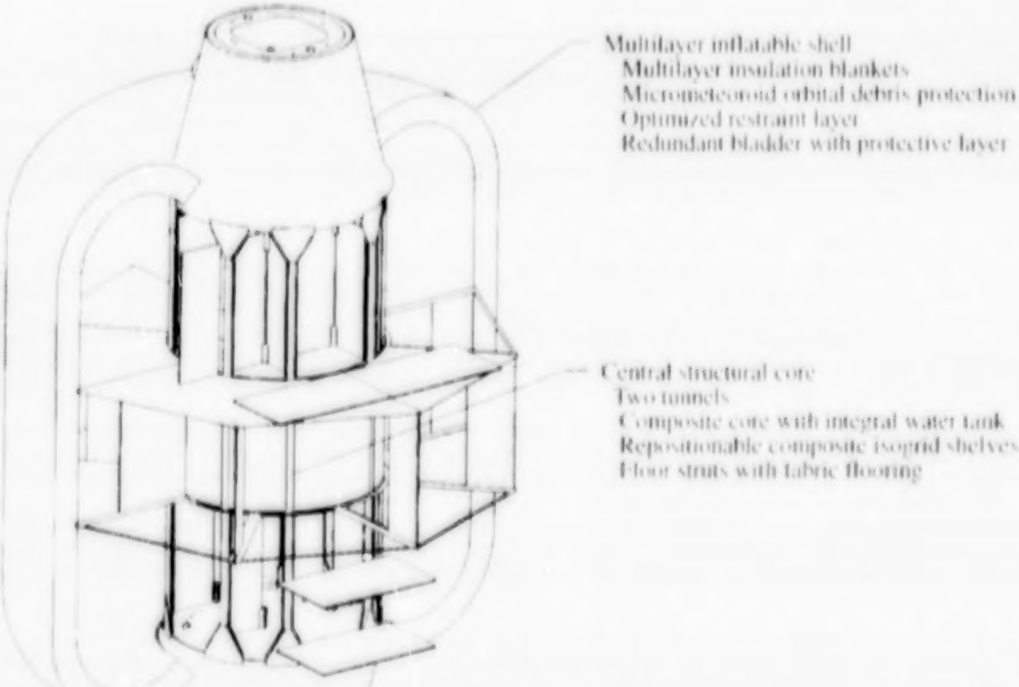

Figure 5.5-1. TransHab features.

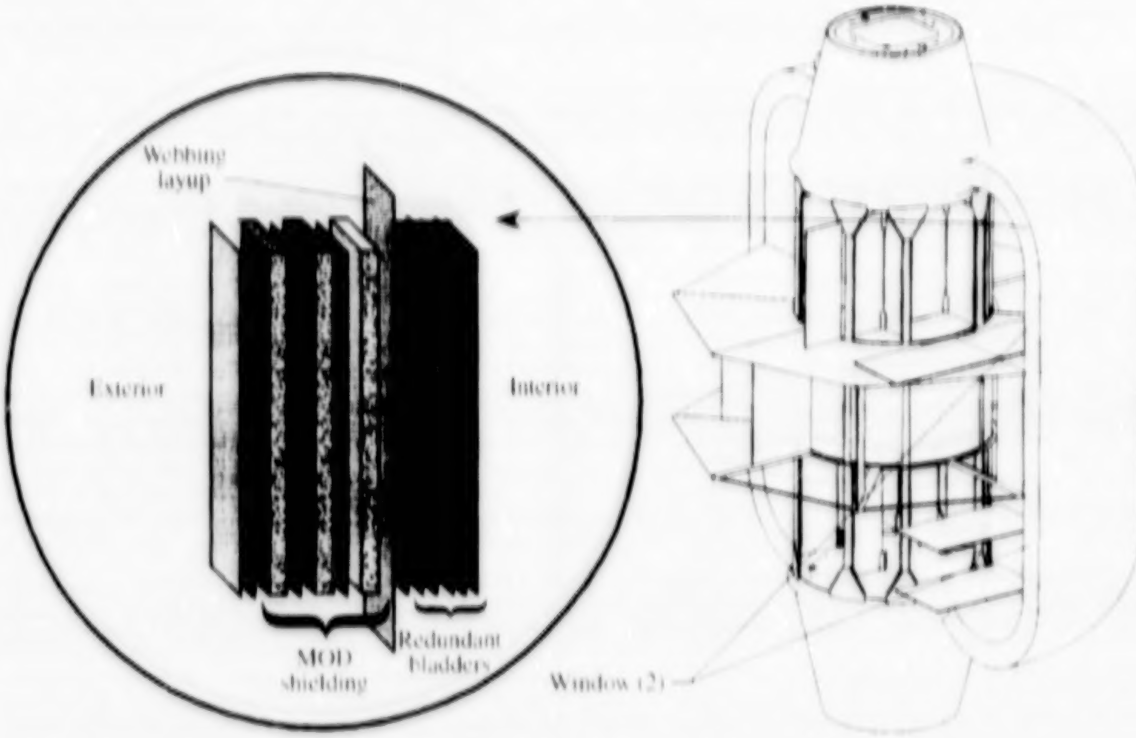

Figure 5.5-2. TransHab multilayer inflatable shell composition.

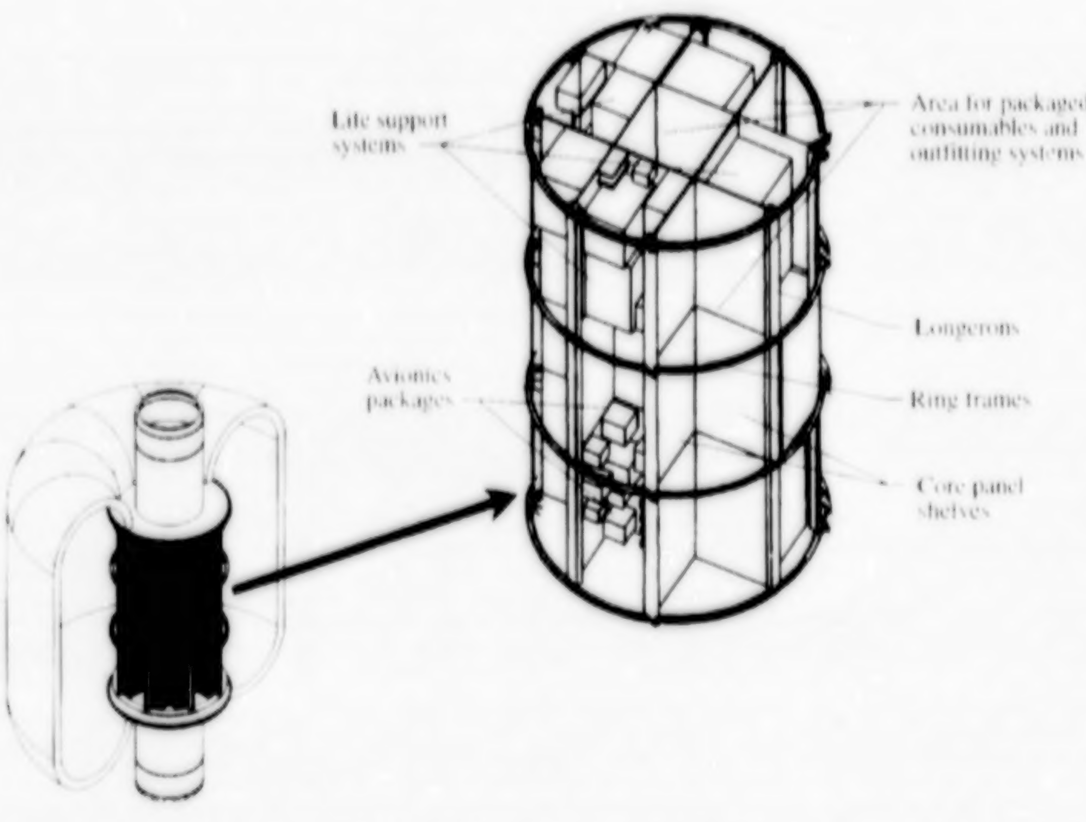

Figure 5.5-3. TransHab core structural layout.

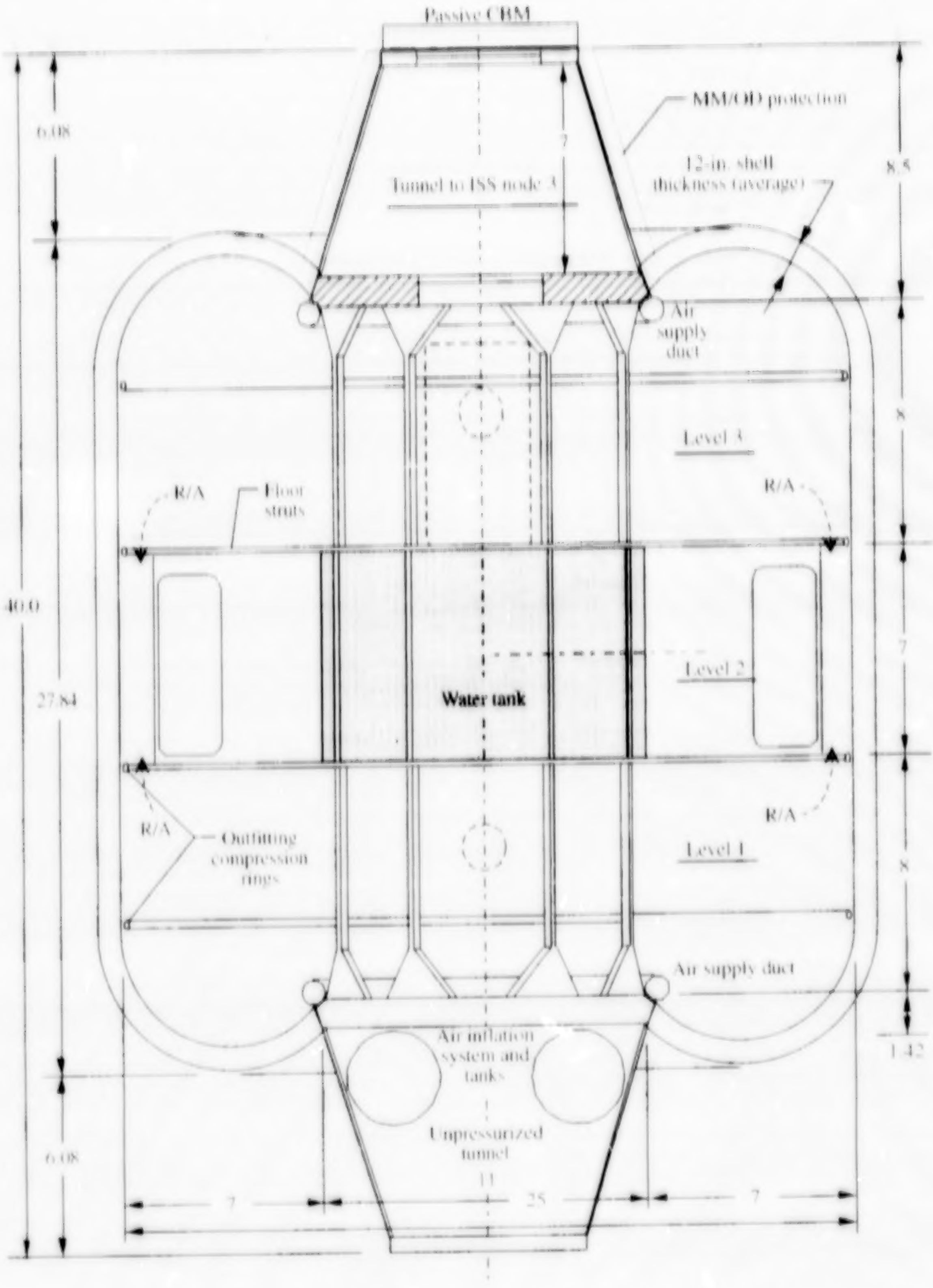

Figure 5.5-4. TransHab cross section. Dimensions are in feet. (Truss sections, radiators, and solar arrays are not shown.)

5.5.3.2. Functional Description and Assumptions

The TH will increase the pressurized volume of the ISS for living space and microgravity experiments. The TH will be delivered to ISS by the Shuttle orbiter. The SSRMS will remove the TH from the orbiter. The common berthing mechanism (CBM) on one end of the core tunnel will dock to an active CBM on a node or module. The ISS crew will inflate and outfit the TH for use. To be used as a reentry vehicle, the TH must be outfitted with an aerobrake. The aerobrake will be assembled and installed at the station.

The assumptions are as follows:

- TH will be added to the baseline AC ISS.
- TH will not interfere with transportation vehicle docking, loading or unloading, and departure operations.
- TH will not alter the microgravity levels in the laboratory modules beyond the ISS microgravity specifications.

5.5.4. Interface Requirements

The TH will be attached to a CBM. Power, thermal, communications, and data connections will be necessary.

5.5.5. Enhanced ISS Configuration

The TH will provide additional volume for crew quarters, laboratory and manufacturing facilities, microgravity, and other facilities. An alternate use of the TH will be as a reentry vehicle for the return of crew, products, and/or wastes from station activities. An aerobrake and heatshield will have to be added to the TH to facilitate its use as a reentry vehicle.

5.5.6. ISS Impacts

5.5.6.1. Installation

The TH will attach to the ISS by using a CBM either at a node port or a module end port. The TH has been proposed as a replacement for the U.S. habitation module (Hab) that is currently baselined to be attached to the port side of node 3. An alternate attachment location for the commercially based TH module could be on the nadir port of node 3. (See figs. 5.5-5 and 5.5-6.) These commercial TH modules would be targeted for research and eventually space-based manufacturing. The number of TH modules and their locations could have significant impacts on the ISS microgravity environment and ISS operations. See sections 5.5.6.3 and 5.5.6.4 for further discussion.

5.5.6.2. Vehicle Configuration

5.5.6.2.1. Mass Properties

The TH adds 35600 lb to the total mass of the ISS. Further study is needed to determine the effects of this mass on ISS moments of inertia.

5.5.6.2.2. Flight Attitude

Initial analysis shows that there is minimal impact to the ISS flight attitude in the Hab position. Further study is needed to determine effects of locating the TH in other locations on the ISS.

5.5.6.2.3. Control

Initial analysis shows that there is minimal impact to the ISS control system in the Hab position. Further study is needed to determine effects of locating the TH in other locations on the ISS.

5.5.6.2.4. Orbital Lifetime

TBD

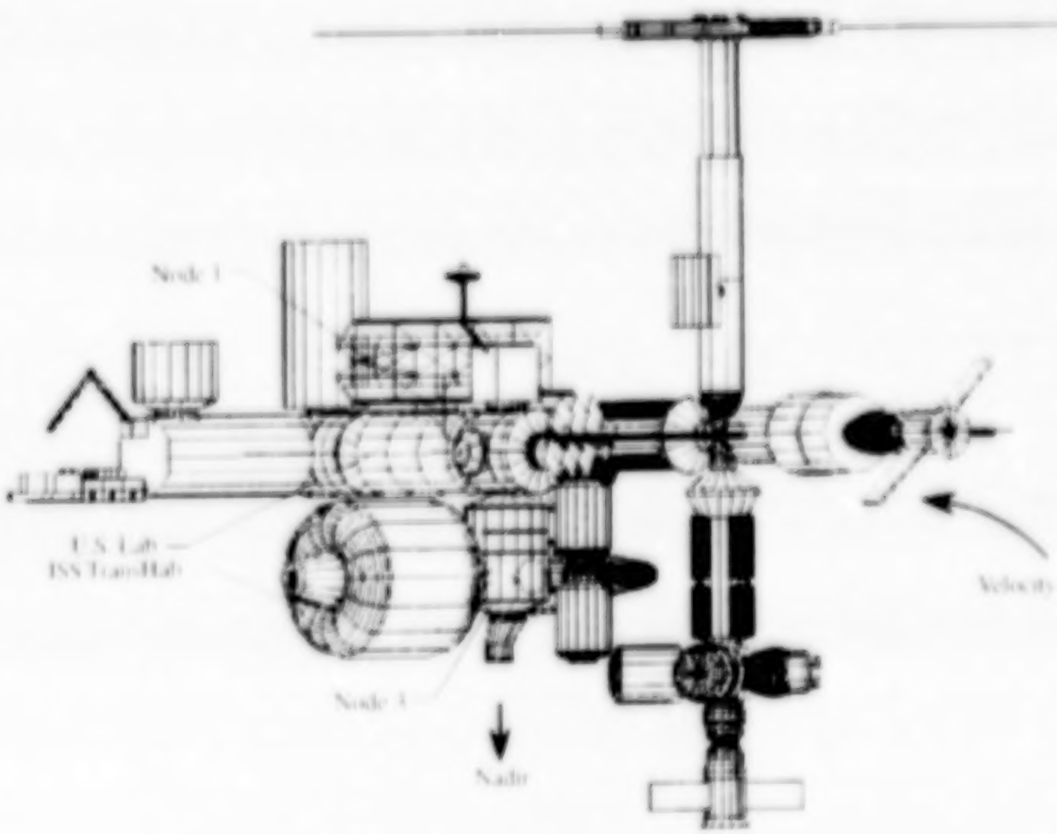

Figure 5.5-5. Proposed ISS accommodation for TransHab on Hab port of node 3. (Truss sections, radiators, and solar arrays are not shown.)

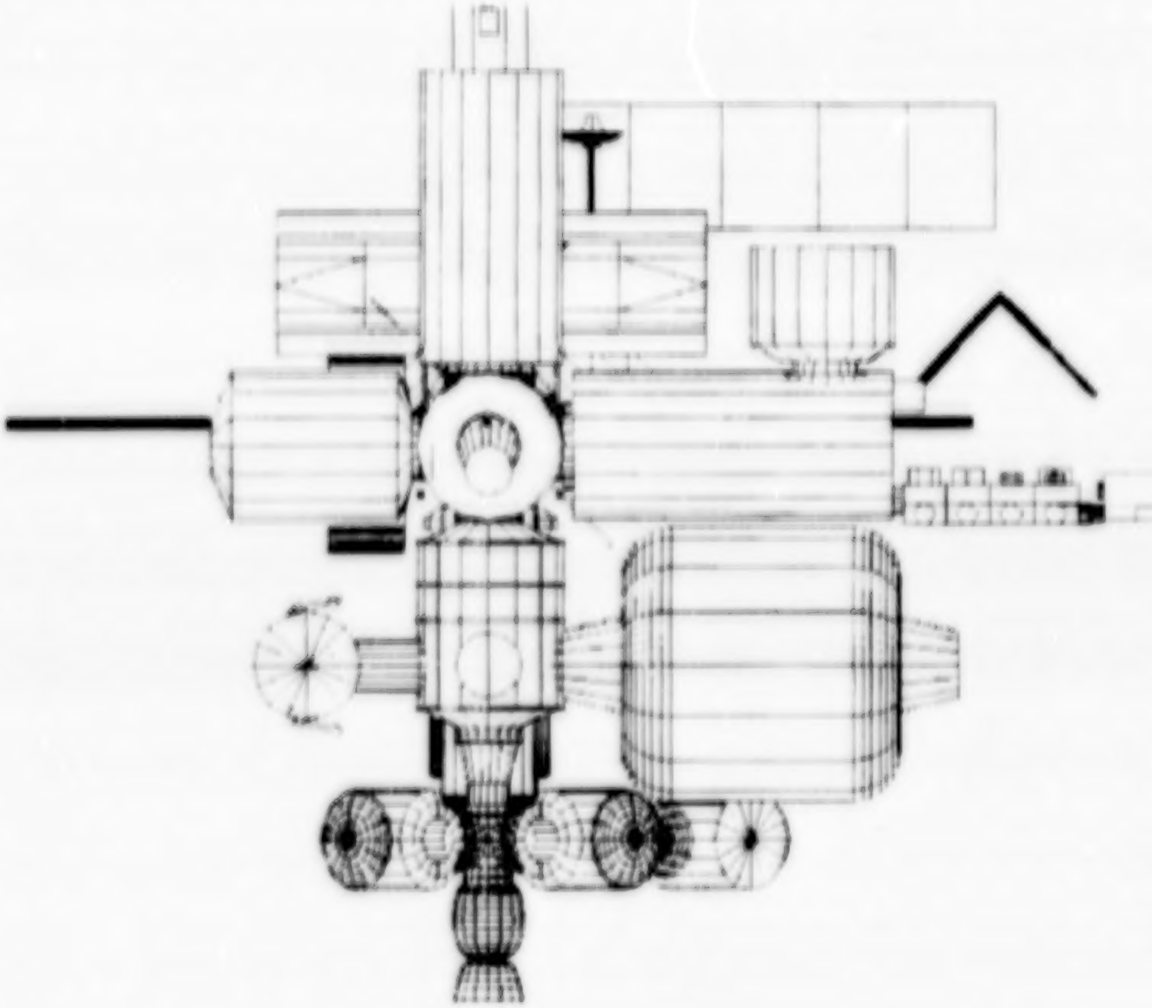

Figure 5.5-6. Forward view of proposed ISS accommodation for TransHab on node 3. (Truss sections, radiators, and solar arrays are not shown.)

5.5.6.3. Operations

5.5.6.3.1. Intravehicular Activity

The TH will need several weeks of IVA for inflation, setup, and outfitting.

5.5.6.3.2. Extravehicular Activity

The SSRMS will remove the TH from the orbiter and berth the TH to an active CBM.

5.5.6.3.3. Ground Support Operations

TBD

5.5.6.4. Utilization

5.5.6.4.1. Microgravity

Initial analysis shows that there is minimal impact to the ISS microgravity levels with the TH in the Hab position. Further study is needed to determine the effects of locating the TH in other locations on the ISS.

5.5.6.4.2. Payload Accommodations

Adding the TH to the ISS will increase the experiment space by TBD racks.

5.5.6.4.3. Payload Operations

TBD

5.5.6.4.4. Visiting Vehicle Operations

TBD

5.5.6.5. ISS Subsystem Impacts

5.5.6.5.1. Command and Data Handling

TBD

5.5.6.5.2. Communications and Tracking

TBD

5.5.6.5.3. Crew Systems

See sections 5.5.6.3.1 and 5.5.6.3.2.

5.5.6.5.4. Environmental Control and Life Support Systems

Additional ECLSS will be mounted within the TH.

5.5.6.5.5. Guidance, Navigation, and Control

TBD

5.5.6.5.6. Power

The addition of the TH will increase the demands on the ISS power system. The additional module will draw power for ECLSS, C&DH, and experiments.

5.5.6.5.7. Propulsion

The addition of the TH will increase the projected surface area of the ISS; thereby, the aerodynamic drag on the station will be increased. This drag will create a need for additional reboost capacity and more frequent reboost activities.

5.5.6.5.8. Robotics

TBD

5.5.6.5.9. Structures and Mechanisms

No additional structure will be needed to install the TH in place of the Hab. Analysis is required to verify the need for additional structure to accommodate the TH in other locations. An analysis also needs to be performed to assess the impact of mounting an aerobrake for the reentry mode of the TH.

5.5.6.5.10. Thermal Control

With the addition of added components, additional thermal radiators will be needed. TH reentry vehicles may provide their own radiator surfaces.

5.6. Tether for ISS Orbit Maintenance

5.6.1. Introduction

Tethers have been used several times to connect spacecraft together since 1967, during the missions of Gemini 11 and 12. Tethers can be used in two ways to propel spacecraft. First, a tether can be severed to send two objects into different orbits. Second, force is exerted on a tether that carries electrical current and moves through a magnetic field. The latter form of propulsion is the basis for this discussion. Information from the document listed in this bibliography (section 5.6.7) was used to compile this section.

5.6.2. ISS Enhancement Goal

An electrodynamic tether deployed on the Space Station (shown in fig. 5.6-1) can provide supplemental reboost to the station and reduce fuel resupply requirements.

5.6.3. Enhancement Specifications for Tether

5.6.3.1. Physical Description

The tether will be 7 km in length, with the first 5 km insulated to protect the station, and the last 2 km bare to act as the electron collecting surface. The mass of the tether alone will be 106 kg. Attached to the end of the tether is a 200-kg endmass whose main purpose is to aid in control of the tether dynamics (by affecting the time constant of librational motion and reducing the tether curvature). The tether will be mounted to a deployer platform, which will be attached to an adjustable boom that is mounted near the center of the ISS module cluster. An example of the tether attached to the adjustable boom is shown in figure 5.6-2.

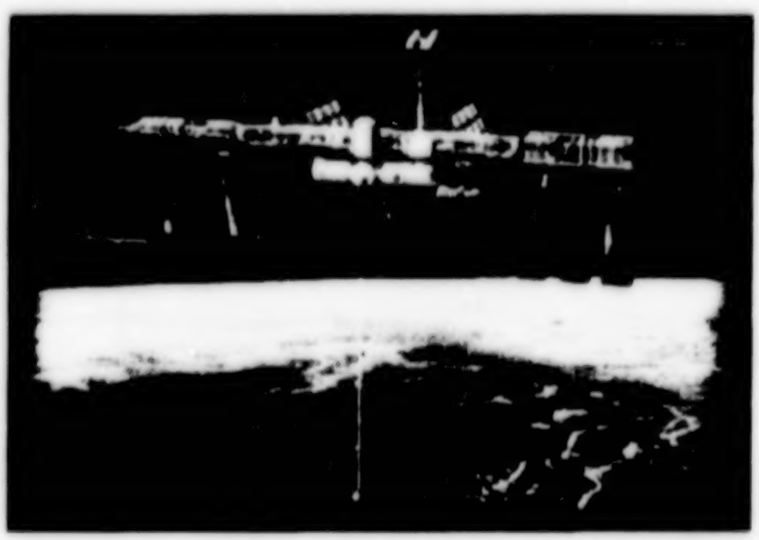

Figure 5.6-1. Tether attached to International Space Station

Figure 5.6-2. Tether attached to adjustable boom.

5.6.3.2. Functional Description and Assumptions

The vector cross product of the current passing through the tether, and the Earth's magnetic field, is proportional to a force applied to the Space Station; for a tether parallel to local vertical and current flow in the nadir direction, the force is made up of one component in the direction of orbital velocity (illustrated in fig. 5.6-3) and another component normal to the orbit plane. Approximately 6 kW of excess power flows through the tether during peak power production periods. The tether will be deployed by attaching one end to the platform and ejecting the deployer (for example, fig. 5.6-4) which doubles as the endmass away from the station. The tether will self-deploy to its full length of 7 km.

5.6.4. Enhanced ISS Configuration Description

The tether is intended to be utilized for AC and beyond. The proposed point of attachment is the starboard port of node 1; however, in this location the tether will interfere with the airlock. A movable boom would allow tuning of the composite center of mass of the ISS and the tether system, which could adjust both the microgravity environment and the torque equilibrium attitude (TEA) of the Station.

5.6.5. Interface Requirements

TBD

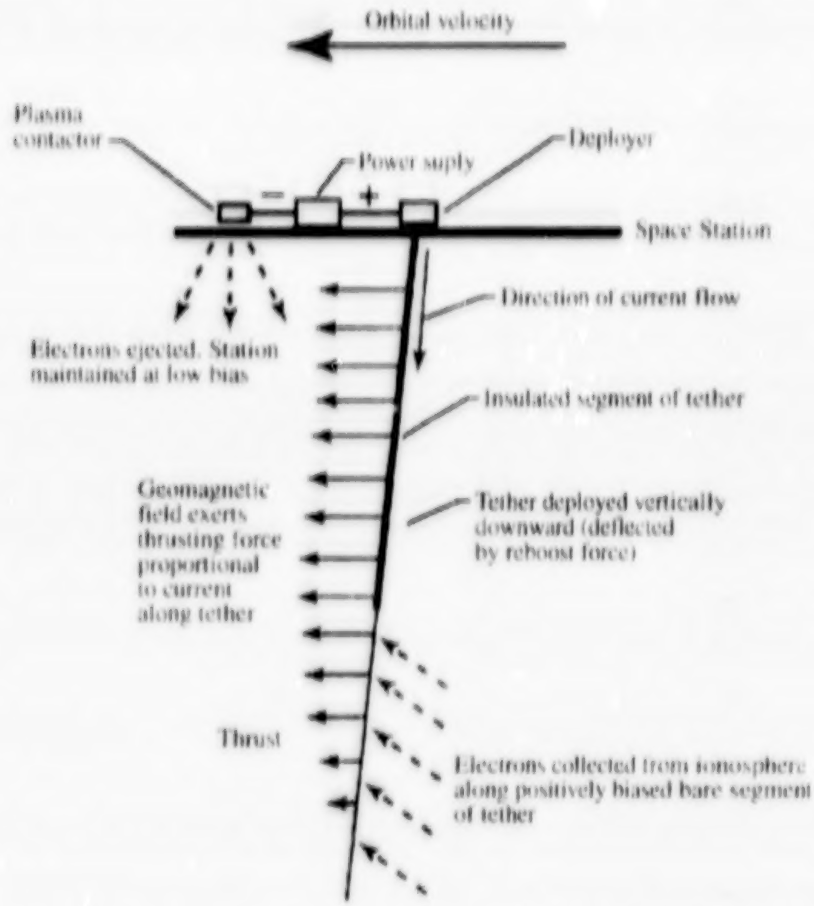

Figure 5.6-3. Electrodynamic tether reboost system for ISS.

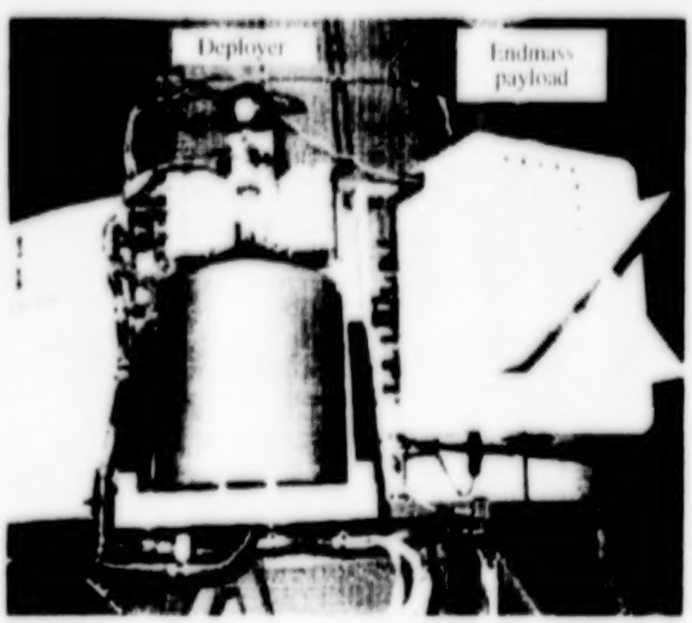

Figure 5.6-4. Small expendable deployer system as flown on Delta II

5.6.6. ISS Impacts

5.6.6.1. Installation

The tether will be delivered via STS and installed during EVA with the aid of the SSRMS onto the starboard port of node 1.

5.6.6.2. Vehicle Configuration

5.6.6.2.1. Mass Properties

An estimate is required for the mass of the platform, boom, and a quantity of replacement tethers (306 kg each). The sheer magnitude of the tether noticeably affects the mass properties of the Station, although the mass of the tether is relatively small. For AC, the center of mass is shifted downward by 4.5 m. Central moments and products of inertia for ISS with the tether attached are TBD.

5.6.6.2.2. Flight Attitude

Changes in the directions of the central principal axes of inertia, together with the tether tension torque and the tether contribution to aerodynamic torque, will change the TEA to some degree. The "tunable" boom can be used to adjust the flight attitude of the Space Station to some extent. The TEA should not be adversely affected by the tether and may be reduced.

5.6.6.2.3. Control

Changes in mass center position will result in changes to the reaction control system (RCS) jet moment arms, and thus affect the ability of the RCS to perform attitude maneuvers, maintain attitude control during reboost, and desaturate the control moment gyroscopes (CMG's). Hence, attitude control propellant usage should be studied. New central principal moments of inertia will alter the "torque derivatives"; consequently, excursions from TEA produced by the momentum manager and CMG momentum peaks will change.

5.6.6.2.4. Orbital Lifetime

Orbital lifetime should be increased greatly by the reboost force exerted when current is flowing in the tether; the decrease in altitude caused by aerodynamic drag when current is not flowing is worth examining.

5.6.6.3. Operations

5.6.6.3.1. Intravehicular Activity

IVA should be unaffected by nominal operation of the tether; however, attention of the crew will be required during discarding and telerobotic replacement of the tether.

5.6.6.3.2. Extravehicular Activity

EVA will be required for installation of the tether system on the Station.

5.6.6.3.3. Ground Support Operations

No impact.

5.6.6.3.4. Visiting Vehicle Operations

Changes to rendezvous and docking procedures for visiting vehicles are TBD. The tether would interfere with the approach from nadir of a visiting vehicle; therefore, the tether will probably have to be discarded or retrieved before a rendezvous.

5.6.6.4. Utilization

5.6.6.4.1. Microgravity

The addition of the tether to the Space Station system shifts the center of mass downward by 4.5 m. This shift will adversely affect the microgravity environment within the laboratories; however, proper tuning of the TEA may ameliorate this.

5.6.6.4.2. Payload Accommodations

The locations of payloads should not be affected since node 1 is the proposed site for attaching the tether.

5.6.6.4.3. Payload Operations

Payload operations must be examined; the presence of a 7-km tether and endmass in the nadir direction potentially affects the viewing of other payloads.

5.6.6.5. ISS Subsystem Impacts

5.6.6.5.1. Command and Data Handling

C&DH is not affected, except perhaps to include information for the tether system itself.

5.6.6.5.2. Communications and Tracking

No impact.

5.6.6.5.3. Crew Systems

Special equipment required for tether replacement is TBD.

5.6.6.5.4. Environmental Control and Life Support Systems

No impact.

5.6.6.5.5. Guidance, Navigation, and Control

A new center of mass may require the relocation of jets for effective control; it must be determined whether reboost, RCS attitude control, and RCS assist of CMG's will be performed with the tether deployed. CMG gain sets (configuration control databases (CCDB's)) may require modification to take into account changes in mass properties, tether contribution to the aerodynamic torques, and the presence of the tether (tension) torque. Disturbance rejection filters may be applied to tether torque.

5.6.6.5.6. Power

Off-peak power of approximately 6 kW will be required to operate the tether. In conjunction with this, connections to a direct-current switching unit (DCSU), direct-current-to-direct-current converter unit (DDCU), and main bus switching unit (MBSU) are required.

5.6.6.5.7. Propulsion

Tether operations will result in a savings of reboost propellant. A new center of mass may require the relocation of jets for effective control.

5.6.6.5.8. Robotics

No impact.

5.6.6.5.9. Structures and Mechanisms

If TEA's are changed significantly, the amount and placement micrometeoroid and orbital debris shielding may be affected.

5.6.6.5.10. Thermal Control

If TEA's are changed significantly, the amount and placement of thermal control material may be affected.

5.6.7. Bibliography

Johnson, L., and Herrmann, M.: International Space Station Electrodynamic Tether Reboost Study. NASA/TM-1998-208538, July 1998.

6. Human Exploration and Development of Space

To be supplied (TBS).

END